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SANDAIRE

San Diego Aircraft Engineering, Inc.

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CONCEPTUAL DESIGN STUDY
OF
AIR BEARING/SUCTION HOLD-DOWN DEVICES
FOR VERTICAL LANDING AIRCRAFT

SAE 77-005

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Advanced aircraft/ship interface concepts are needed to improve air operations aboard existing and future small air capable ships. This study is a synthesis and evaluation of air bearing/suction hold-down device concepts for automatically securing vertical landing aircraft to moving ship decks during launch, recovery and traversing operations. Specifically, the feasibility of conceptual hold-down devices is analyzed based on system installation

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20. factors (size, weight and power), performance and development risk. The analysis resulted in a recommendation for further evaluation of a base-line rigid skirt hold-down system.

ACCESSION for

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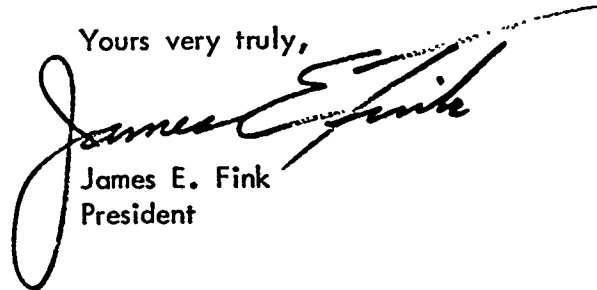
Gentlemen:

Reference: Contract No. N62269-77-C-0046

Sandaire is pleased to submit the final report of the referenced contract to perform a conceptual design study of air bearing/suction hold-down devices for vertical landing aircraft.

The study determines the feasibility of developing an air bearing/ suction device that will instantaneously secure a vertical landing, fixed or rotary wing, aircraft to the moving deck of a non-aviation ship. The system also provides for translation of the aircraft on the deck while maintaining the required hold-down force.

Three systems, elastic trunk, rigid skirt, and the Bernoulli principle, are described in detail in the report. All are feasible and meet the requirements of the contract; however, the rigid skirt system offers the best potential for further development.

Sandaire has enjoyed working with the Naval Air Development Center on this promising hold-down system for vertical landing aircraft. If you have any questions regarding the report, please contact Mr. Paul D. Sorensen, Manager of Advanced Design.

Yours very truly,

James E. Fink
President

JEF:dec

SANDAIRE

San Diego Aircraft Engineering, Inc.

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CONCEPTUAL DESIGN STUDY

OF

AIR BEARING/SUCTION HOLD DOWN DEVICES
FOR VERTICAL LANDING AIRCRAFT

SAE 77-005

March 21, 1977

Submitted to:

Commander
Naval Air Development Center
Warminster, Pennsylvania 18974

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SANDAIRE

PREFACE

Presented herein are the final results of a Conceptual Design Study of Air Bearing/Suction Hold Down Devices for a Vertical Landing Aircraft.

The objective of this study is to determine the feasibility of using air bearing/suction hold down devices to automatically secure vertical landing aircraft (fixed and rotary wing) to moving ship decks instantaneously upon touchdown. The device must provide the necessary hold down force while permitting translation of the aircraft on the flight deck. The device must have minimal impact on aircraft design, be compatible with available power sources and deck surface conditions.

Specifically, conceptual designs of three (3) separate hold down systems were developed. The relative merits of the three systems are compared as to weight, power required, size, hold down force, translation force, development risk, and aircraft installation factors.

The three conceptual designs studied are:

(1) Inflatable Elastic Trunk System

(2) Rigid Skirt System

(3) Bernoulli System (uses blowing rather than suction to develop hold down force)

The Rigid Skirt System seems to offer the most promise for further study and development.

This report is submitted in accordance with requirements specified in Contract No. N62269-77-C-0046.

SANDAIRE

TABLE OF CONTENTS

INTRODUCTION

The purpose of this study is to determine the feasibility of developing an air bearing/suction hold down device that will instantaneously secure a vertical landing aircraft to the moving deck of a non-aviation ship, upon touchdown. In addition, the system must provide for translation (spotting) of the aircraft on the deck simultaneously with providing the required hold-down force. The system must remain in operation until the aircraft is tied down on the deck and the engines are shut down.

Three separate concepts were developed to provide the required hold-down force. The three systems are as follows:

      1. Elastic Trunk System   –   (Figure 11)

      2. Rigid Skirt System   –   (Figure 13)

      3. Bernoulli System   –   (Figure 15)

Each of the above systems are designed to be mounted externally under the fuselage, in a faired housing, and do not penetrate the basic aircraft mold lines. In a new design, the systems can easily be incorporated into the basic lines of the aircraft. The hold-down systems are mounted on hydraulically operated four-bar mechanisms that raise and lower the suction hold-down system as required. In each case, the basic landing gear is retained on the aircraft and serves to react the suction hold-down force.

The Elastic Trunk System and the Rigid Skirt System are similar in operation and differ only in the manner in which the air cushion is formed. In the case of the Elastic Trunk System, the air cushion (cavity) is formed by inflating an elastic membrane around the periphery of a rigid platform (similar to air cushion landing systems). The trunk forms a seal at the deck to permit the cushion to be evacuated by an exhaust fan. The differential pressure across the platform creates a downward force on the aircraft through the retraction/deployment mechanism. The suction hold-down force is then reacted at the deck by the aircraft landing gear. The suction force acts perpendicular to the deck and does not have a side force acting to slide the aircraft off the sloping deck as does the aircraft weight component (Figure 1).

The Rigid Skirt System operates in exactly the same manner as does the Elastic Trunk System except the cushion cavity is formed by a rigid fiberglass skirt. The skirt has a rubber seal around its lower periphery to form a seal at the deck. The skirt is free-floating (in relation to the platform), and contact with the deck is maintained by pneumatic snubbers (or springs).

The Bernoulli System uses blowing rather than sucking to develop the required suction hold-down force. A rigid platform, with a shaped lower surface, is

brought into contact with the deck. A low pressure/large volume fan exhausts air at the center of the platform. Pressure will build up under the platform and lift the platform sufficiently to form an air gap around the outer edge creating an air bearing. The high velocity of the airflow lowers the static pressure under the platform (high dynamic pressure) to less than ambient pressure. The resulting pressure differential will react on the aircraft to hold it on the deck. As in the other systems, the reaction on the main landing gear is increased perpendicular to the flightdeck. Hydraulic pressure in the retraction/deployment system is used to transfer the hold-down force to the aircraft.

All of the three systems studied show good potential to be developed into a workable air bearing/suction hold-down system. The incremental weight of the systems range from 0.8% to 1.4% of the landing gross weight of the aircraft. This is assuming a suction force to weight ratio of 0.5 where suction forces range from 10,000 to 20,000 pounds.

The Rigid Skirt System would be first choice for further development. The technical risks are minimal; power requirements are low; translation forces are low; the overall size of the package is reasonable; and the weight of the system not significantly higher than the lightest weight Bernoulli System.

GENERAL REQUIREMENTS AND ASSUMPTIONS

A meeting between NADC and Sandaire personnel was held at NADC on January 27, 1977 to establish the general requirements, ground rules and assumptions for this feasibility/conceptual design study. The criteria agreed upon are outlined below.

1. Flight Deck

   (a) Flat steel or aluminum flight deck with anti-skid surface.

   (b) Static conditions (ignore inertia forces).

   (c) Slope of flight deck limited to maximum roll angle of 20 degrees.

2. Operational Conditions

   (a) Wind over deck and aerodynamic drag of aircraft is neglected.

   (b) Standard atmospheric conditions.

   (c) The aircraft will establish a hover condition over the flight deck (height to be determined). The throttle then retarded to idle power (or minimum required to operate hold-down system) allowing the aircraft to descend to the deck.

   (d) Brakes are locked.

   (e) Pilot can control hold-down force.

   (f) System can be operated from ship's power after engine shutdown.

   (g) Low translation forces, due to hold-down system, to permit movement of aircraft.

   (h) Engine bleed air can be used only prior to hover mode (inflate trunk, etc).

   (i) Hold-down system uses available aircraft electrical power at low power setting.

3. Hold-Down System

   (a) The hold-down system is to be an add on to the basic aircraft. (Conformal carriage, etc.)

   (b) Basic landing gear system to be retained on aircraft.

   (c) Incremental weight of the hold-down systems studied will consider only the add-on weight (neglect structural changes to aircraft).

4. Study Requirements

   (a) Determine required hold-down force as a function of deck angle, coefficient of friction and aircraft lift/weight ratio.

   (b) Develop a minimum of three (3) candidate conceptual air bearing/ suction hold-down systems. These systems will be developed for a selected landing gross weight (base point). Three-view drawings will be made in sufficient detail to define the system and permit weight, size and performance to be estimated.

   (c) Performance characteristics of the candidate systems are to be determined. These characteristics include: size, weight, power required, hold-down force, and translation force. The effect of aircraft gross weight on performance is to be included.

   (d) Determine relative merits of the candidate conceptual designs in terms of developmental risks, aircraft installation factors, weight, and performance. Recommend a preferred system.

REQUIRED HOLD-DOWN FORCE

The forces acting on the aircraft while setting on the flight deck are shown in Figure 1. These forces assume static conditions (no inertia forces) and neglect any aerodynamic drag forces on the aircraft. All of the forces are assumed to be reacted on the basic landing gear of the aircraft. Any drag forces due to the suction hold-down device contacting the deck are neglected.

The summation of forces perpendicular to the deck are:

$$\leq F_v = W \cos \theta - L + F_s$$

The summation of forces parallel to the deck are:

$$\leq F_H = F_v - W \sin \theta$$

where:
- W = Gross Weight of A/C (Lbs)
- L = Lift (Lbs)
- F_s = Suction Force (Lbs)
- θ = Deck Roll Angle (Deg)
- μ = Coefficient of Friction

To prevent the aircraft from sliding on the flight deck, the value of $\leq F_H$ must be equal to or greater than zero. Therefore, the required coefficient of friction is:

$$\mu_{Req} = \frac{\sin \theta}{\left[\cos \theta - \frac{L}{W} + \frac{F_s}{W} \right]}$$

The above equation was solved for various values of deck roll angle, lift/weight ratio and suction force/weight ratio. The results of these calculations are shown i Figure 2.

The Mechanical Engineers Handbook (Marks), Fourth Edition, gives the coefficient of sliding coefficient for a tire on a wet brick surface as 0.52 (5 mph). This is for a tire with circumferential grooves. It has been assumed that the wet brick surface is comparable to a flight deck with an anti-skid surface. For purposes of this study, we have used a coefficient of friction (sliding) of 0.5 on a wet flight deck.

To determine the lift/weight ratio at touchdown, the following assumptions were made.

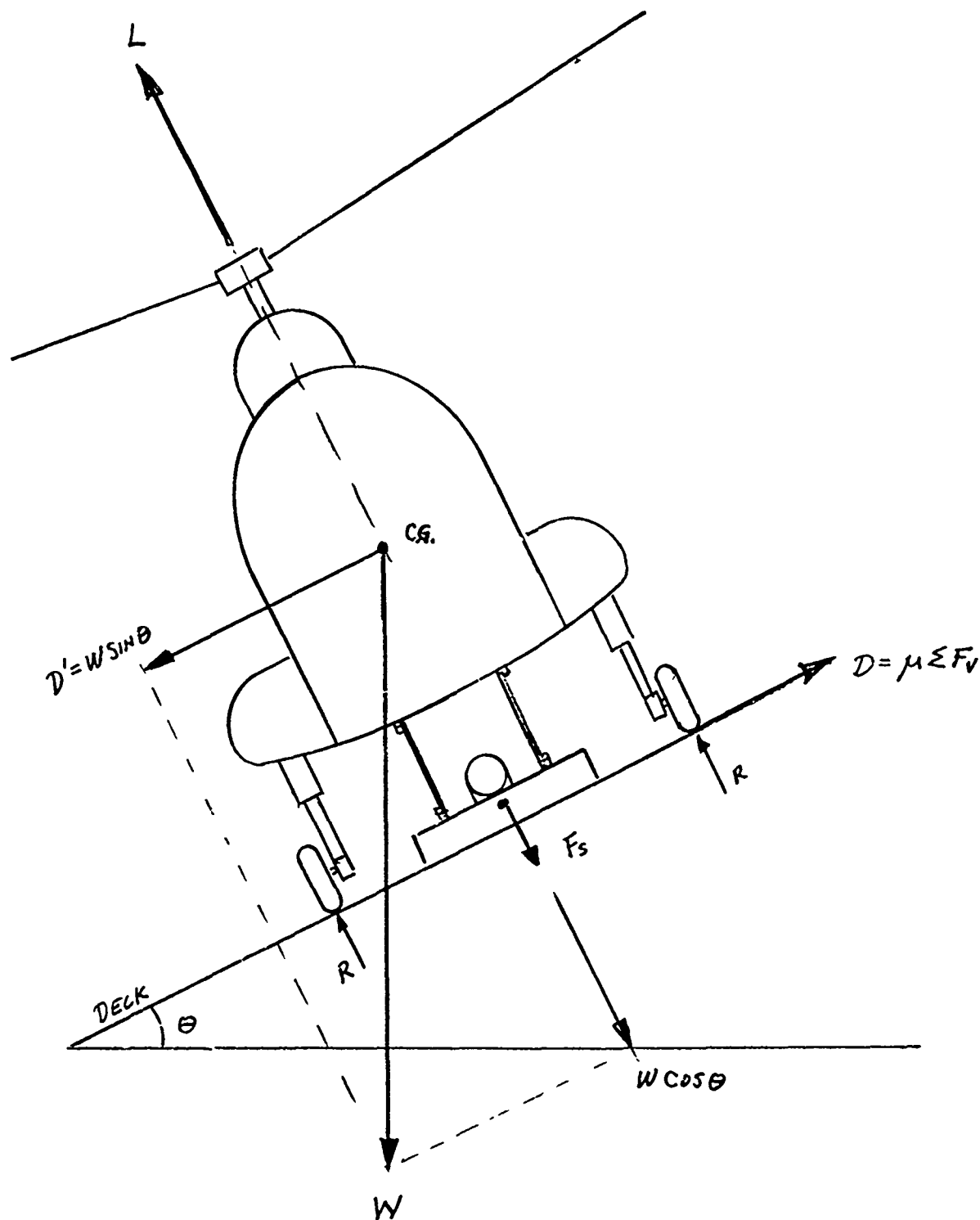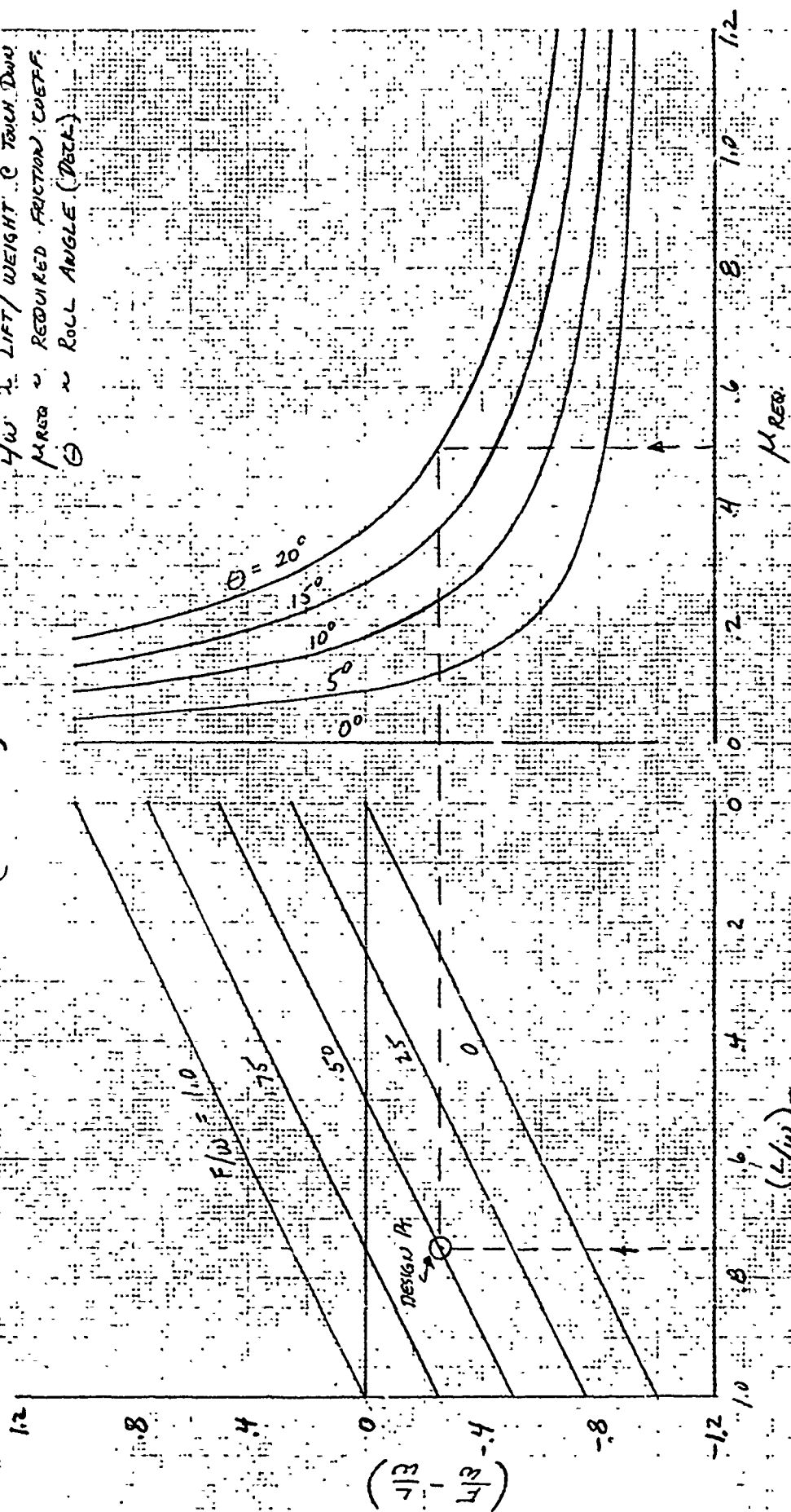# FIGURE 1

FORCES ACTING ON AIRCRAFT

FIGURE 2

EFFECT OF LIFT, SUCTION FORCE
AND ROLL ANGLE ON REQUIRED
FRICTION COEFFICIENT TO
PREVENT SLIDING OFF DECK
(STATIC)

$F/W \sim$ SUCTION FORCE/WEIGHT
$L/W \sim$ LIFT/WEIGHT @ TOUCH DOWN
$\mu_{REQD} \sim$ REQUIRED FRICTION COEFF.
$\theta \sim$ ROLL ANGLE (DECK)

(1) The vertical landing aircraft will hover over the landing spot (on the deck). The power is chopped and the aircraft is allowed to drop to the deck.

(2) The aircraft velocity is equal to the velocity of the ship.

(3) The brokes on the aircraft are set prior to touchdown.

(4) The aircraft lift (engines) decays parabolically with time.

$$\frac{L}{W} = 1 - \left(\frac{t}{K}\right)^{.5}$$

where:

$$K = \frac{\Delta t}{\left[\left(\frac{L}{W}\right)_H - .5\left(\frac{L}{W}\right)_H\right]} = \frac{\Delta t}{.25}$$

$(L/W)_H$ = Lift/Weight at Hover = 1.0

Δt = Time for L/W to drop to 50% of hover L/W

Using the above equations, and assuming various values of Δt, the lift/weight ratio was calculated as a function of time after throttle moved to idle. (Figure 3).

Equations were then developed to determine the lift/weight ratio at touchdown as a function of hover height and engine decay rate (Δt).

$$a = g\sqrt{t/k}$$

$$v = gt^{1.5}/1.5\,(k)^{.5}$$

$$s = gt^{2.5}/3.75\,(k)^{.5}$$

$$t = \left[3.75\,(k)^{.5}\,s/g\right]^{.4}$$

where: a = vertical acceleration (ft/sec^2)
s = hover height above deck (ft)
t = time to descent to deck (sec)
v = vertical velocity at touchdown (ft/sec)

The above equations were solved assuming several values of hover height and Δt. The results of these calculations are shown in Figure 4. Examination of

FIGURE 3

EFFECT OF TIME ON LIFT/WEIGHT RATIO AFTER POWER LEVER MOVED TO IDLE.

$$\frac{L}{W} = 1 - \left(\frac{t}{K}\right)^{.5}$$

$$K = \frac{\Delta t}{.25}$$

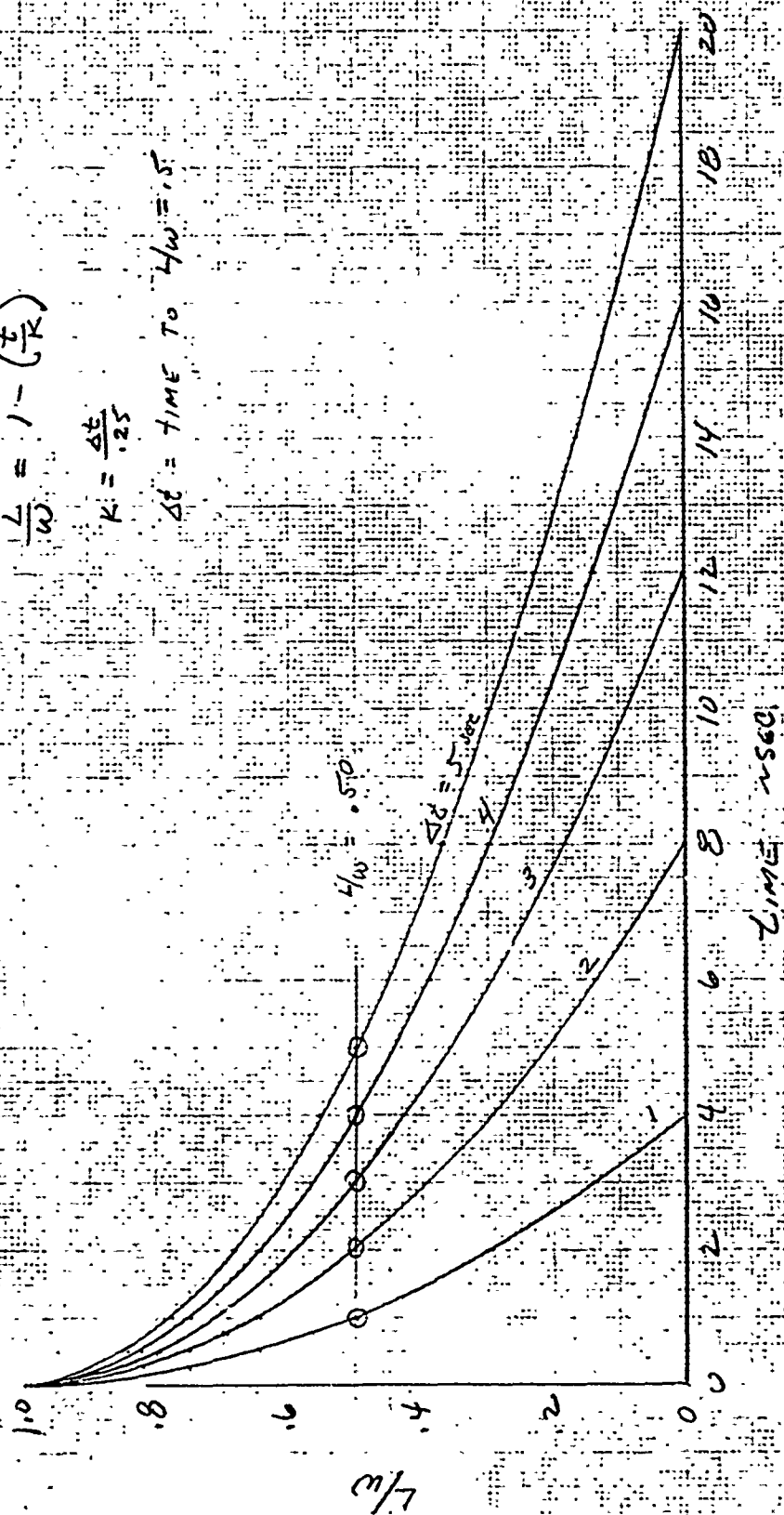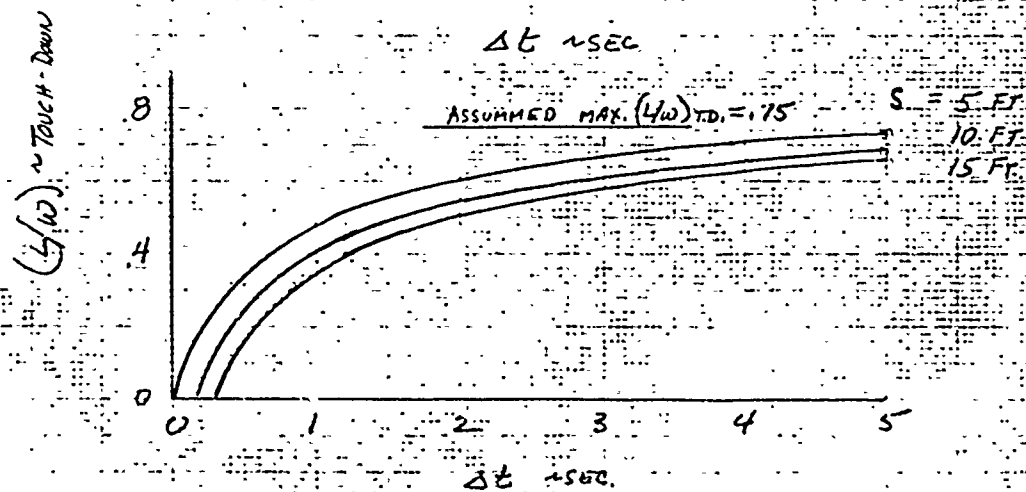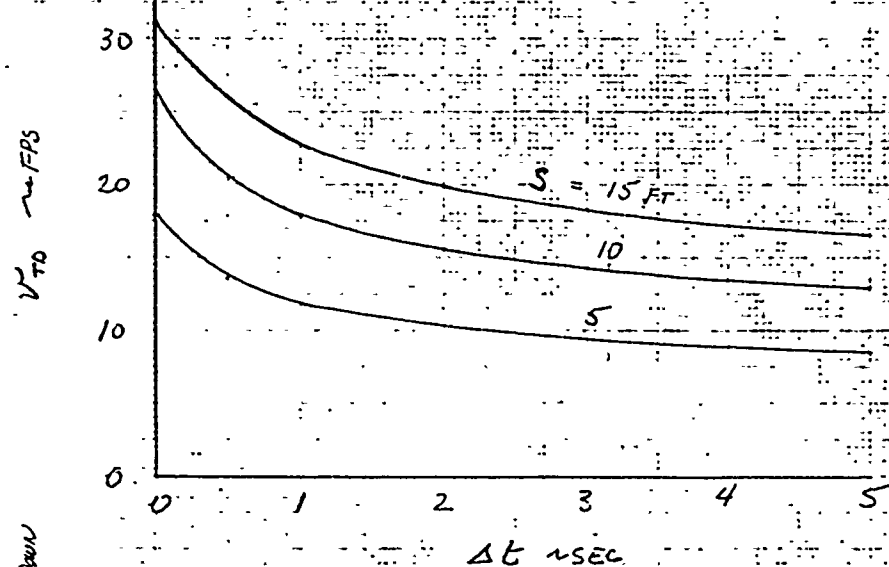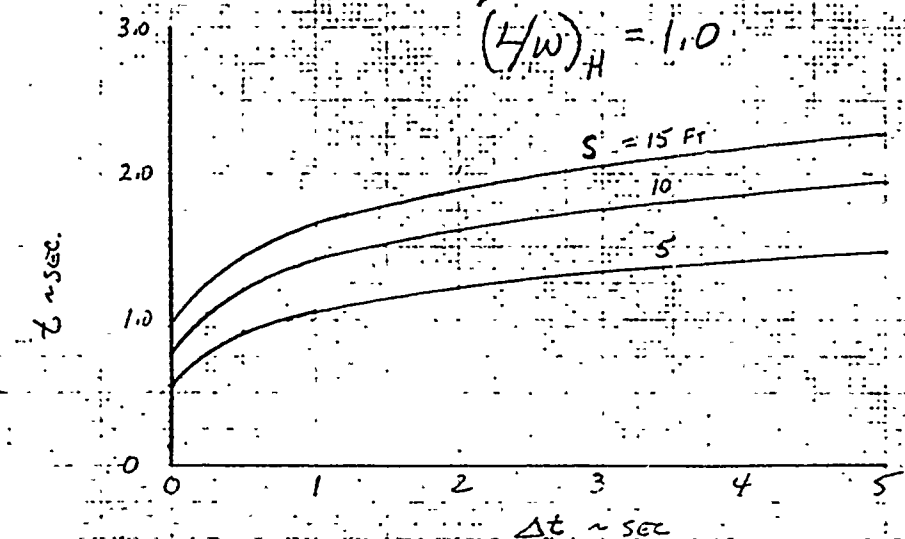$$\Delta t = \text{TIME TO } L/W = .5$$

FIGURE 4
EFFECT OF LIFT DECAY ON
ON $(L/w)_{TD}$, TIME, AND VERTICAL
VELOCITY AT TOUCH DOWN
$(L/w)_H = 1.0$

these data shows that the most critical condition (highest values of L/W at touchdown) occur at low hover heights and low engine decay rates. Therefore, for purposes of this study, a value of (L/W) = .75 at touchdown was selected as being a reasonable maximum value to be expected during a vertical landing.

To determine the value of suction force/weight ratio to be used for this conceptual design study, the following criteria were used:

$$\theta = 20^\circ$$

$$(\mu)_{Req} = .5$$

$$(L/W)_{T.D.} = .75$$

These data result in a value of suction force/weight ratio (F/W) required of 0.5. (Figure 2). This value of (F/W) was then used for the three conceptual designs presented herein.

Figure 5 has been included to show the effect of (F/W) and cushion pressure on the cushion area required to develop the required hold-down force.

FIGURE 5

EFFECT OF CUSHION PRESSURE
ON REQUIRED CUSHION AREA

W = LANDING WEIGHT ~LBS
F = SUCTION FORCE ~LBS
P_c = CUSHION PRESS. ~PSI
A_c = CUSHION AREA ~FT²
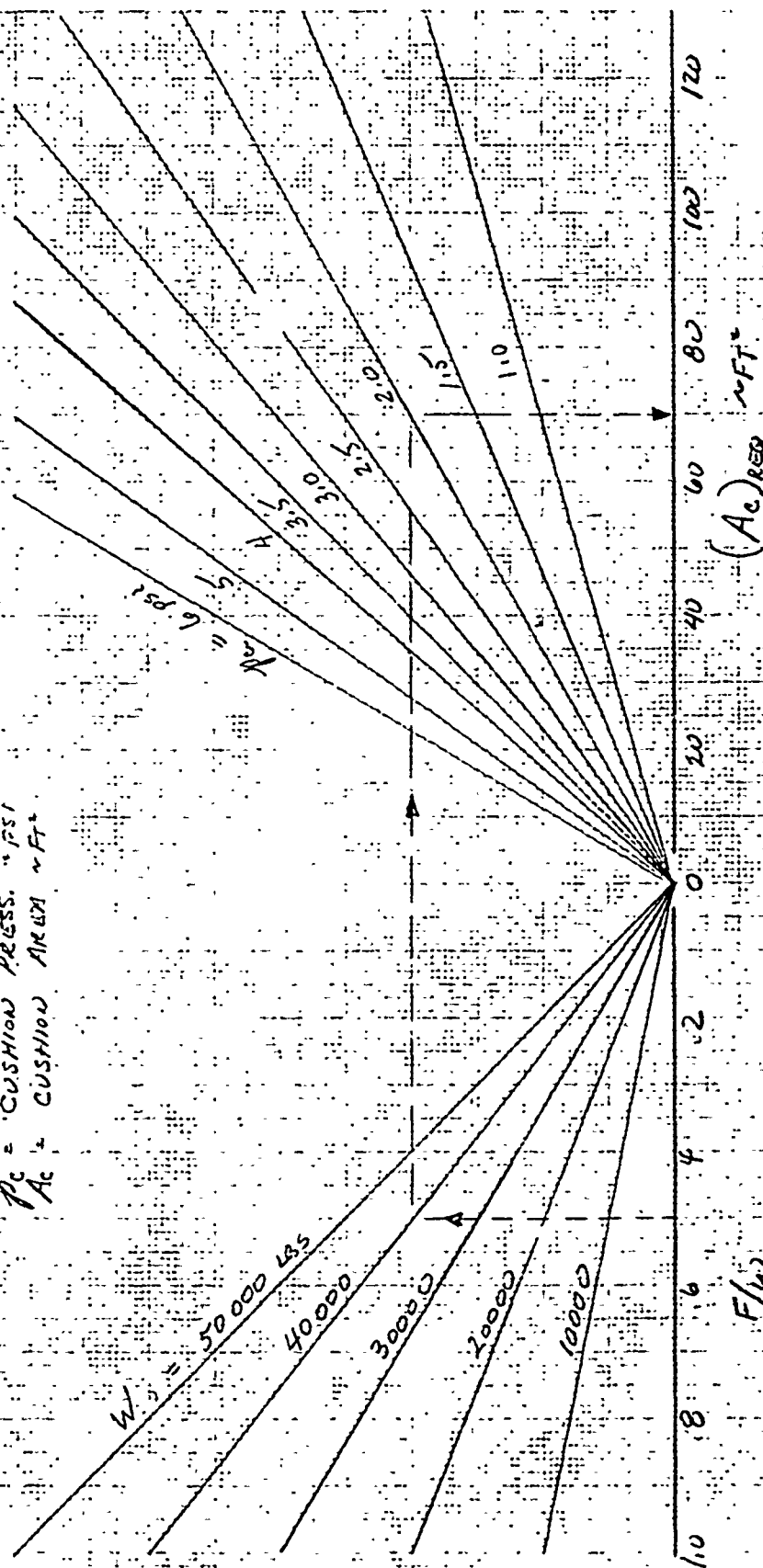
AIR MOVING DEVICES

Several types of air moving devices were considered. These included centrifugal fans, axial fans, mixed flow fans, and tip-driven fans.

The tip-driven fans are good candidates for this type of application because of their relatively light weight, size and high pressure ratio. However, they were not used in this study because they required the use of either engine bleed air or an auxiliary power source to supply the high pressure, high volume gas flow to operate the fans. The ground rules prohibit the use of bleed air and the added weight of an A.P.U. appeared to be prohibitive.

Centrigual fans were available that would develop cushion pressures down to approximately -2.5 psig; however, the volume flow of these fans is very low for reasonable size units. The volume flow was so low that it was feared that even modest amounts of leakage into the cushion would destroy the required negative cushion pressure.

A mixed flow fan was selected for the Base Point Elastic Trunk and Rigid Skirt Systems (Figures 6 and 7). This fan offers a good compromise between cushion pressure and available volume flow (p_c = -1.824 psig @ Q = 140 cfm). For the parametric studies (suction forces greater than 10,000 pounds), the selected fan was ratioed (in proportion to the air cushion periphery at the ground tangent) to determine its size, weight, power required, and volume flow.

The fan (AMD) required for the Bernoulli System is entirely different than for the other two systems. In this case, a low pressure ratio fan delivering very large volumes of air is required. Therefore, an axial flow fan (Figures 8 and 9) was selected for the base point design. This fan delivers 5,000 CFM @ a total pressure rise across the fan of .444 psig (std atmos). For suction forces greater than the base point (F_s = 10,000 lbs), the required volume flow was increased in proportion to the cushion exit periphery. The fan size, weight, and power required was ratioed in proportion to the required volume flow.

Both of the fans selected for these conceptual design studies use 200 volt, 400 cycle A.C. current, which is fairly standard on aircraft. Figure 10 shows the fan characteristics for each system as a function of suction hold-down force.

The scaling factors used to size the fans in this study are given on the next page.

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Effect of RPM

$$Q = Q_0 (N/N_0)$$

$$P_T = P_{T_0} (N/N_0)^2$$

$$BHP = BHP_0 (N/N_0)^3$$

Effect of Density (N = const)

$$P_T = P_{T_0} (w/w_0)$$

$$BHP = BHP_0 (w/w_0)$$

$$Q = Q_0$$

Effect of Fan Diameter

$$Q = Q_0 (D/D_0)^3 (N/N_0)$$

$$P_s = P_{s_0} (D/D_0)^2 (N/N_0)^2$$

$$BHP = BHP_0 (D/D_0)^5 (N/N_0)^3$$

$$W_T = W_{T_0} (D/D_0)^2$$

If the fan tip speed is assumed constant, then $(N/N_0) = (D_0/D)$:

$$Q = Q_0 (D/D_0)^2$$

$$P_s = P_{s_0}$$

$$BHP = BHP_0 (D/D_0)^2$$

Power Equations

$$BHP = Watts \times \eta / 746$$

$$\eta = Q \times P_T / 33,000 \, BHP$$

$$BHP = \sqrt{Watts \times Q \times P_T} / 4967.4$$

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Miscellaneous Equations

$$Q = A_v$$

$$W_f = wQ$$

$$q = w\,V^2/2g$$

where:

A	=	Area	$(Ft^2\quad)$
BHP	=	Brake Horse Power	
D	=	Diameter	$(Ft\quad)$
N	=	RPM	
η	=	Efficiency	
P_s	=	Static pressure	(PSFG)
P_T	=	Total pressure	(PSFG)
Q	=	Volume flow	(CFM)
q	=	Velocity head	(Lbs/Ft^2)
V	=	Velocity	(Ft/Sec)
W_T	=	Weight	(Lbs)
W_f	=	Mass Flow	(Lbs/Sec)
w	=	Density	(Lbs/Ft^3)

Subscript

o	=	Original Condition

FIGURE 6

JOY/TASK AXIVANE® FAN
Aircraft, Vehicular and Electronic Fan Specifications

JOY AEROPRODUCTS

A-1.50-1

MOTOR

Speed R.P.M.: 22,500
Volts: 200 - 3 Phase
Type: 400 Cycle - A.C.

Enclosure: Total
Duty: Continuous

FAN

Part No.: 15650-1
Design Rating CFM: 150
Pressure Inches W.G.: 55

Weight (Pounds): 12.2
Construction: Aluminum
Performance

FLOW

See reverse side for performance curve.

FIGURE 7

FAN P/N 15650-1

MOTOR: 22,500 RPM
2007/374/00

AIR DENSITY: 0.075 LB/FT³
FAN TESTED BLOWING

FIGURE 8 18

JOY/TASK AXIVANE® FAN
Aircraft, Vehicular and Electronic Fan Specifications

JOY AEROPRODUCTS

A – 45.00

MOTOR
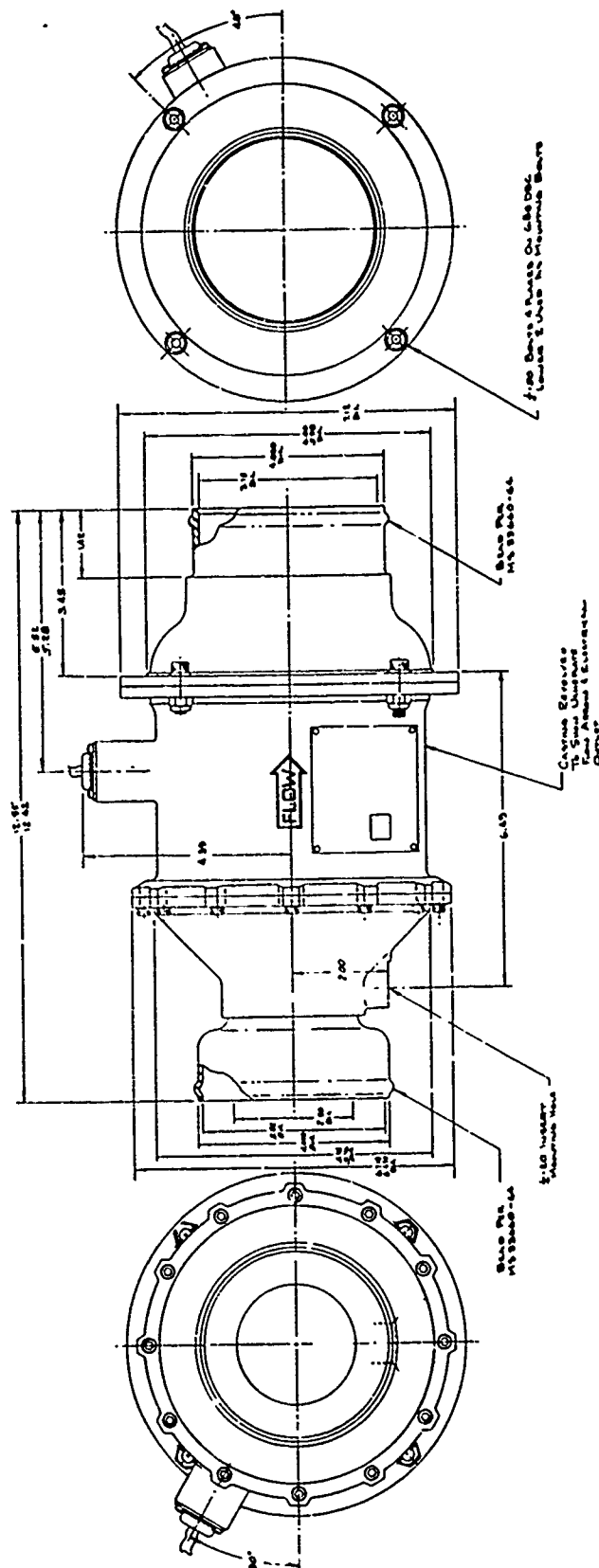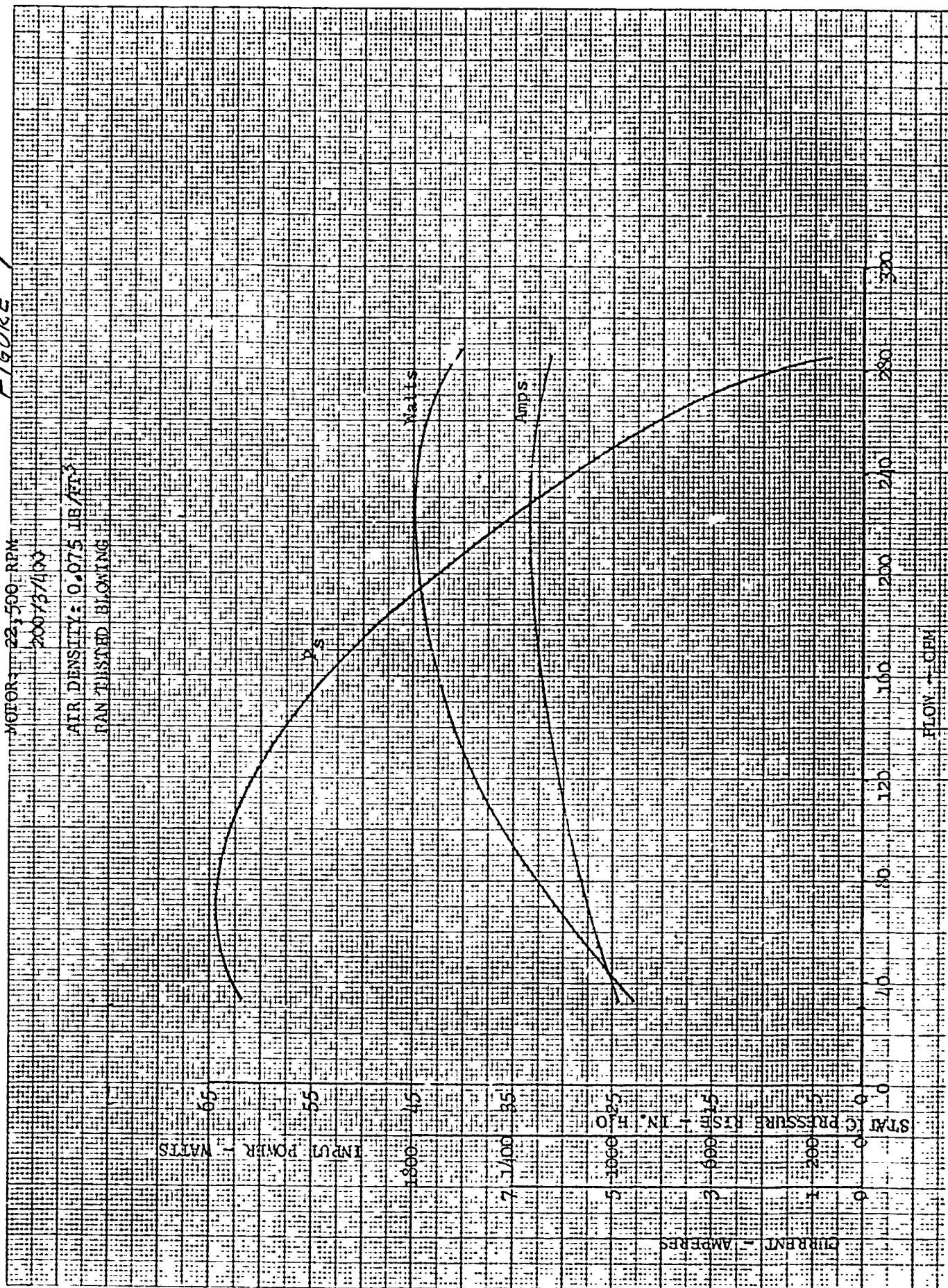
Horsepower: 14.5
Speed R.P.M.: 11,300
Volts: 200
Type: 400 Cycle – A.C.

Enclosure: Open
Duty: Continuous
Design Spec.: A & N

FAN

Part No.: X7G2-311A
Model No.: AVR 100 – 50D1501
Design Rating CFM: 4500
Pressure Inches W.G.: 14.65 Ps

Weight (Pounds): 26.5
Construction: Aluminum
Performance Curve: C-3375
Design Spec.: A & N
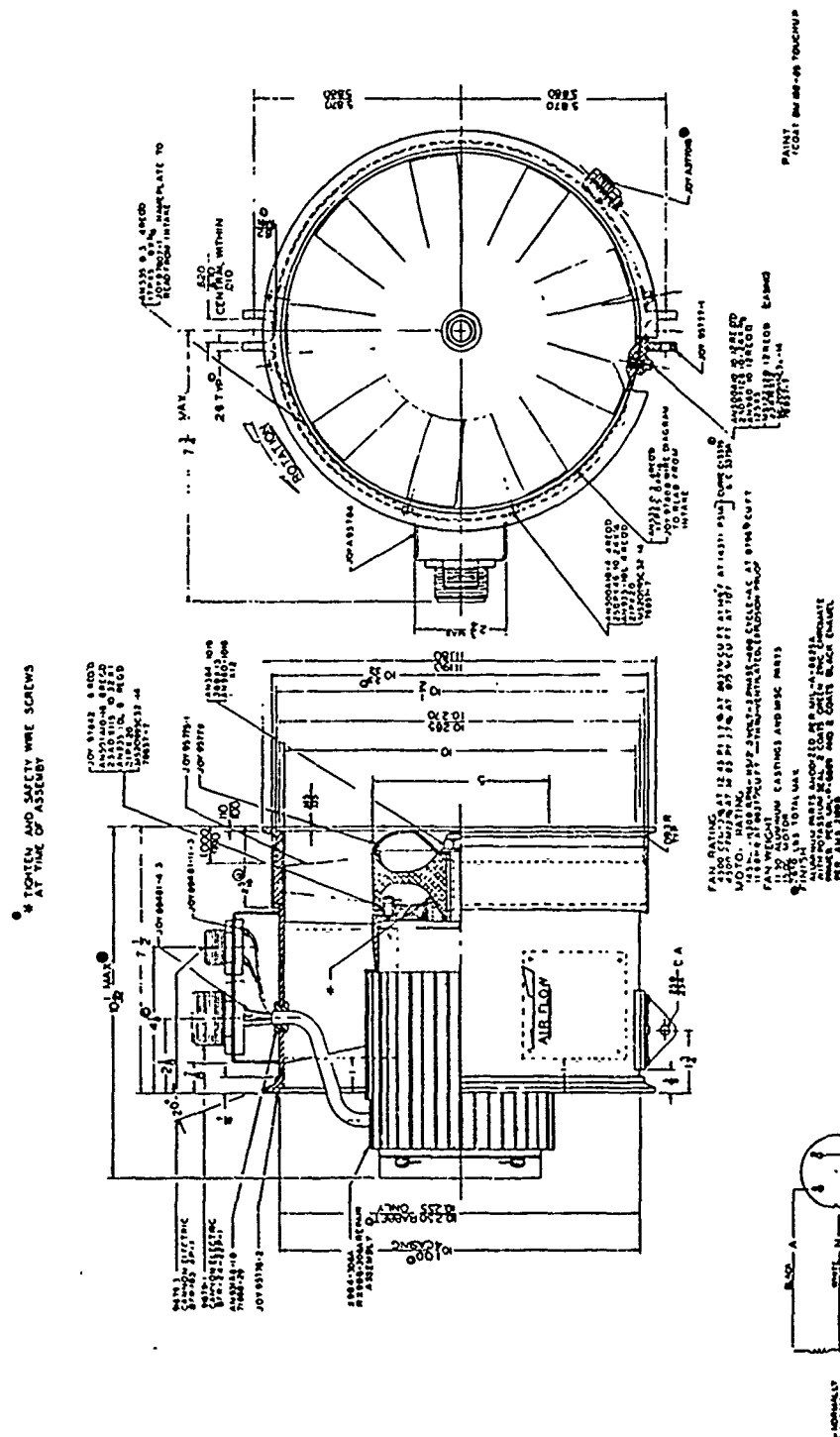
See reverse side for performance curve.

Figure 7

JOY MANUFACTURING COMPANY
NEW PHILADELPHIA, OHIO
NOVEMBER 5, 1958 SK/sd

PERFORMANCE BY TEST
JOY UNIT NO.: X702-341-A
TEST S/N 98, PROTOTYPE N83N
FAN MOTOR S/N 1UD63
DENSITY: 0.0637 #/cu.ft.

C-3375
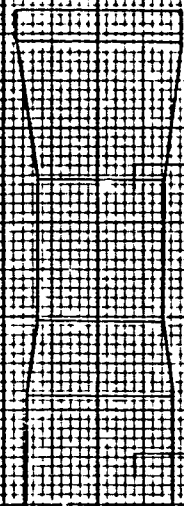
Figure 10

FAN CHARACTERISTICS

Volts = 200   (400 Cycle A.C.)

SYSTEM	ELASTIC TRUNK			RIGID SKIRT			BERNOULLI		
SUCTION FORCE (Lbs)	10,000	15,000	20,000	10,000	15,000	20,000	10,000	15,000	20,000
Watts	2,030	2,486	2,871	2,030	2,486	2,871	12,127	14,400	16,000
BHP	1.74	2.14	2.47	1.74	2.14	2.47	12.54	14.89	16.55
Dia (In)	7.12	7.88	8.47	7.12	7.88	8.47	12.0	13.08	13.78
Length (In)	12.55	13.89	14.92	12.55	13.89	14.92	10.0	10.9	11.49
Volume Flow (CFM)	140	171.5	198	140	171.5	198	5,000	5,800	6,597
Weight (Lbs)	12.2	14.94	17.25	12.2	14.94	17.25	26.5	31.47	34.96
Cushion Press (psig)	-1.824	-1.824	-1.824	-1.824	-1.824	-1.824	-2.431*	-2.637*	-2.756*

*Average Static Pressure Under Platform (psig)

SYSTEM DESCRIPTIONS

The base point conceptual designs of this study assume an aircraft with a landing gross weight of 20,000 pounds. The design suction hold-down force/weight ratio is 0.5; therefore, the design suction force is 10,000 pounds.

All three systems are similar in location and the method used for retraction and deployment. The systems are located in faired housings attached on the underside of the fuselage. For this study, the entire system (except for pilot controls) is external to the basic mold lines of the aircraft (add on). The faired housing is assumed to be constructed of fiberglass. For a new aircraft, it is entirely feasible that the system could be partially or wholly enclosed within the basic lines of the aircraft.

In order to provide a stable retraction/deployment system in all three axes and allow for installation of the necessary pumps, fans and ducting, the twin parallelogram configuration shown in Figures 11, 13, and 14 was selected. Due to the nature of the loading and the resolution of forces in the load-carrying members, it was felt that this configuration would have the effect of reducing point loads and moments, with a consequent reduction in weight over a single trapeze system. Primarily, no matter what system is selected, a vertical tension force must be applied for hold-down. It was assumed that sufficient structure internal to the aircraft is already available at selected load points in order to transfer these loads. As an alternative, it would be possible to add structure externally at the cost of additional weight.

Secondarily, fore and aft shearing forces must be transmitted as the vehicle translates across the deck. These forces will be small, but for design purposes a maximum force of 1200 pounds was assumed. Side shearing forces may be expected during some landing and deck handling operations (turning), but it is expected that this magnitude will be relatively small.

In the retracted condition, the entire dead weight of the hold-down system will be supported by latches located in the housing. These latches will be automatically deactivated, and the fans activated, by the pilot when he commands deploy. Deployment then takes place by the actuation of twin hydraulic cylinders (Figure 17). Upon full deployment (limited by mechanical stops, sensing switches and/or solenoid valves), the hydraulic cylinders become shock struts.

At touchdown (bottom of stroke), solenoid valves are activated to apply hydraulic pressure to the cylinders, thus retracting the platform to a predetermined position.

Conceivably, deployment could be tied to the landing gear actuation mechanism and become automatic, but it is felt that retraction, at least, should be at the option of the pilot. In any event, retraction is accomplished by overriding the

hold-down operation sensing devices, shutting down the fans, and maintaining an up load in the cylinders. In the "up" position, the automatic latches are engaged and hydraulic pumps are shut down. The unit is then ready for recycling.

Elastic Trunk System – In this system (Figure 11), a honeycomb platform is suspended from the retraction/deployment trapeze, described above. A prestretched elastic rubber/nylon membrane (similar to the Buffalo ACLS) is attached to the lower surface of the platform (10 inches wide at the outer periphery). The prestretch causes the elastic material to lie flat against the platform when the trunk is not inflated. Upon deployment of the system, low pressure engine bleed air is used to inflate the trunk to approximately 3.7 psig. For this study, the prestretch of the elastic material (not inflated) was 64% of its original unstretched length. In the inflated condition, the elastic material is 280% of its original length. These stretch ratios were chosen to stabilize the trunk in both the stowed and inflated conditions. In the inflated condition (free air), the trunk radius is approximately 5.7 inches and extends 8.5 inches below the platform. When the trunk is in contact with the deck at the design cushion to trunk pressure ratio ($p_c/p_T = -.5$), the ground tangent point is 8 inches below the platform and 6.9 inches inboard of the outer edge of the platform (Figure 12). The trunk is sucked inwards due to the differential pressure between the ambient pressure and the cushion pressure. This is just opposite to air cushion landing systems, where the cushion pressure is greater than ambient.

For suction forces greater than 10,000 pounds, the elastic trunk dimensions, cushion pressure, and trunk pressure are held constant. The platform size is increased to give the required cushion area. The fan air flow required is increased in proportion to the trunk ground tangent perimeter.

The Elastic Trunk System is deployed such that the trunk will contact the deck just prior to the aircraft reaching static ground line condition (fan operating). That is just before the main landing gear oleos are compressed to the normal static position. This will cause the trunk to flatten against the deck. The flattening of the trunk will absorb the initial shock (in conjunction with the shock struts) and reduce the size of the air cavity under the platform. As the trunk flattens against the deck, air is forced out under the trunk (relief valves may be required); therefore, a partial vacuum will be formed in the cushion as the landing gear oleos extend back to their static position after impact. Also, the hydraulic cylinders are activated at impact and will start moving the platform up to its operating height. The hold-down force is developed by the time the aircraft reaches static conditions.

The optimum operating height of the platform is such that the trunk is just tangent to the deck. At this position, air is sucked in under the trunk by the fan and an air bearing is created. For this condition, translation forces will be negligible. However, if the platform is too high, then the suction hold-down force will be lost due to excessive air flow into the cushion. On the other hand, if the
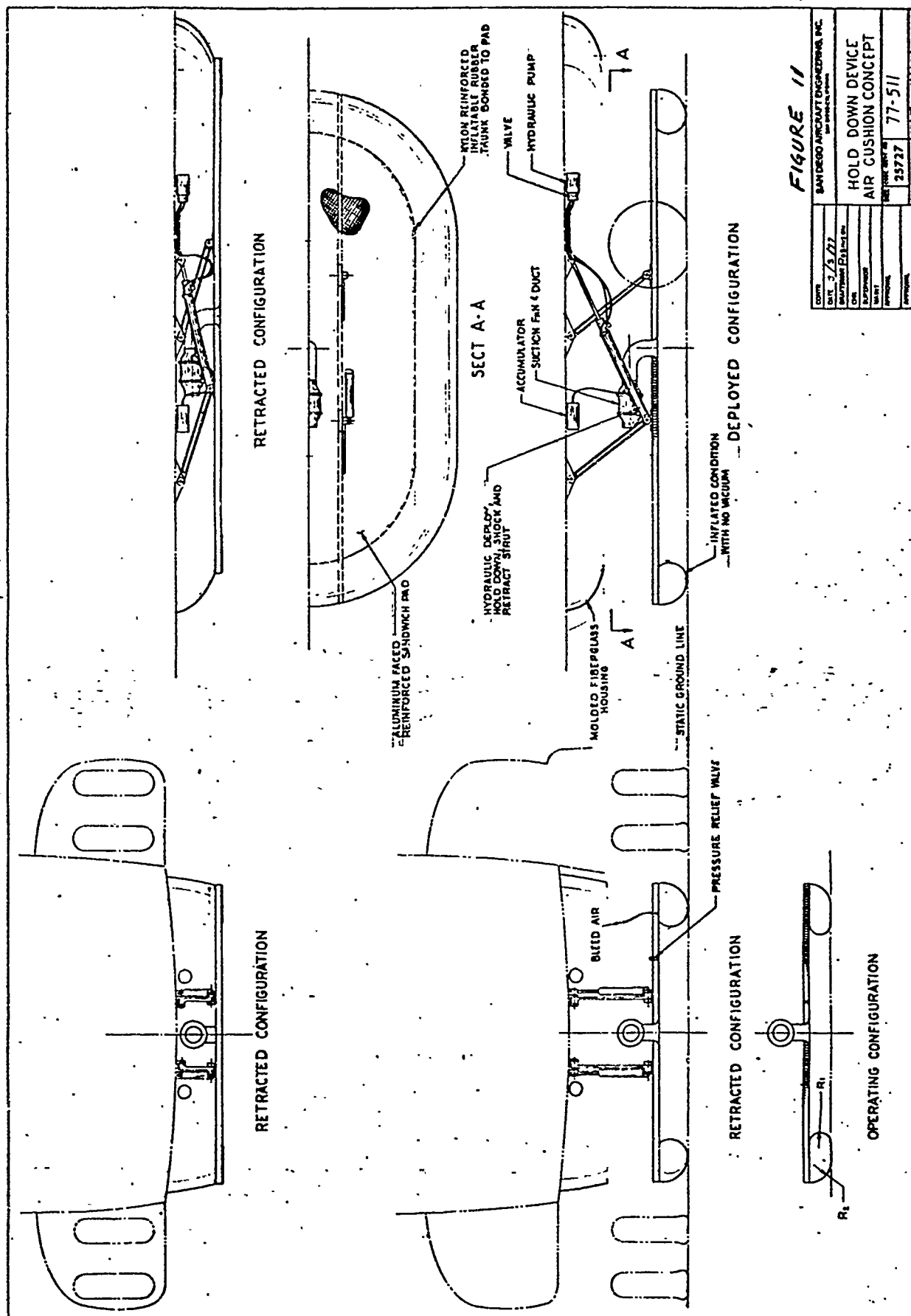
RETRACTED CONFIGURATION

RETRACTED CONFIGURATION

NYLON REINFORCED
INFLATABLE RUBBER
TRUNK BONDED TO PAD

VALVE

HYDRAULIC PUMP

SECT A-A

ACCUMULATOR

SUCTION FAN & DUCT

DEPLOYED CONFIGURATION

HYDRAULIC DEPLOY,
HOLD DOWN, SHOCK AND
RETRACT STRUT

ALUMINUM FACED
REINFORCED SANDWICH PAD

INFLATED CONDITION
WITH NO VACUUM

MOLDED FIBERGLASS
HOUSING

STATIC GROUND LINE

PRESSURE RELIEF VALVE

BLEED AIR

RETRACTED CONFIGURATION

R_1

R_2

OPERATING CONFIGURATION

FIGURE 11

SAN DIEGO AIRCRAFT ENGINEERING, INC.

HOLD DOWN DEVICE
AIR CUSHION CONCEPT

25727 | 77-511

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FIGURE 12.

BASE POINT ELASTIC TRUNK SYSTEM

$F_s = 10000$ LBS
AREA CUSHION = 38.07 FT^2
AREA PLATFORM = 52.76 FT^2
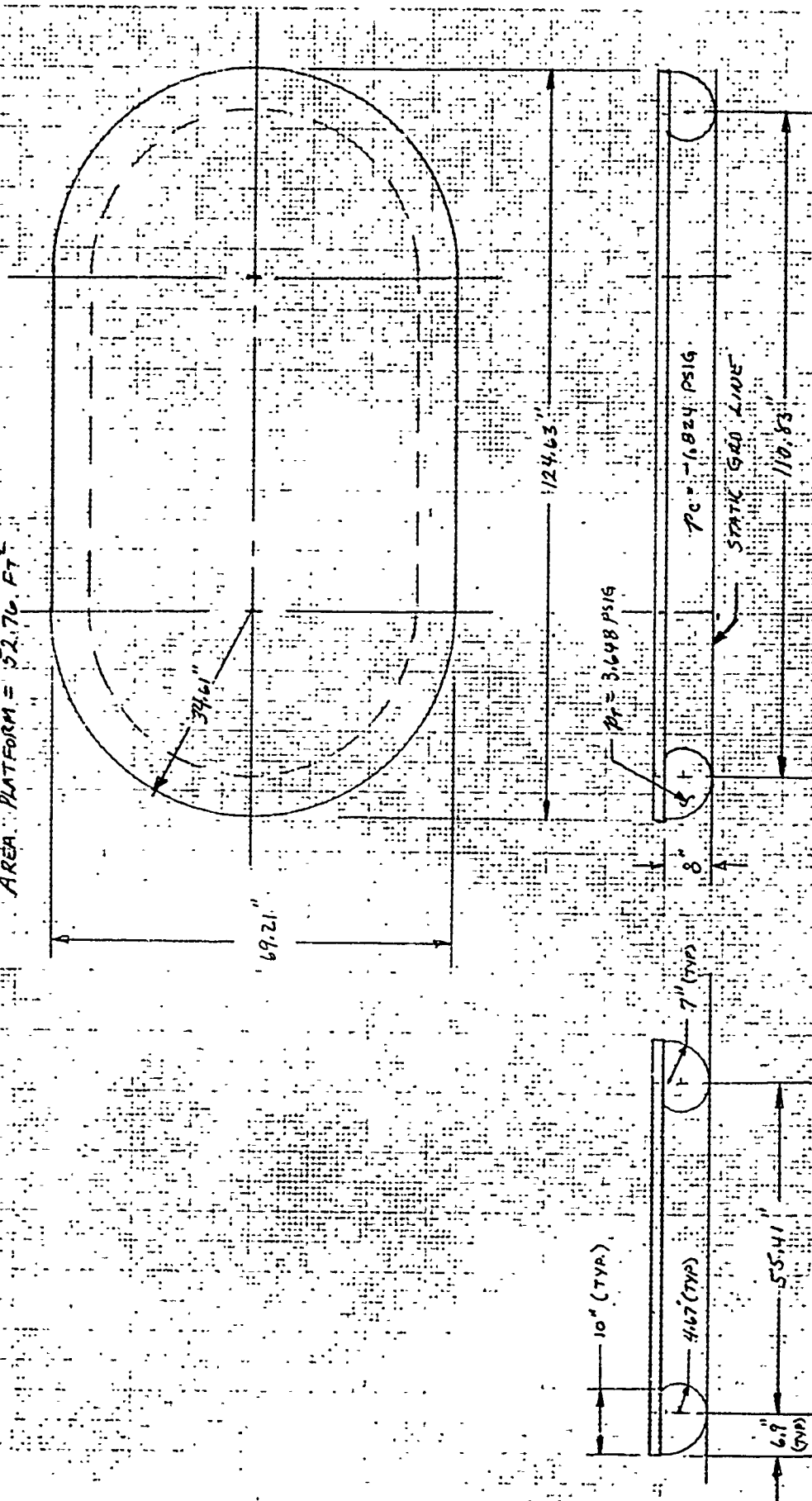
platform is too low, the trunk will be flattened against the deck. The flattening of the trunk against the deck will result in a lift force equal to the trunk pressure times the trunk footprint area. This is not objectionable for hold down, but it does result in high translation forces (Drag = Coefficient of friction times the trunk reaction force). Teflon rub strips added to the trunk at the ground tangent will greatly reduce the translation forces ($\mu = .05$).

It is felt that by applying a lift force on the system hydraulic cylinders, just less than the obtainable hold-down force, will insure a minimum of trunk footprint area, thus minimizing the translation forces. Possibly pressure sensors and/or a feeler wand may be required to properly position the platform. Also relief valves to allow air flow into the cavity may be required to prevent fan stall.

A study would be required to develop the Elastic Trunk System. This study would include investigating trunk materials, trunk sizing, system definition, and further search for higher pressure ratio fans.

Some of the advantages of this system are:

(1) Excellent shock absorption, especially in conjunction with the shocks struts.

(2) Relatively low air flow requirements.

(3) Ease of trunk stowage. (See Item 4 of disadvantages).

(4) Relatively low risk.

(5) Rapid initial suction due to forcing air out of cushion cavity on landing impact.

(6) Small fan with low power required.

(7) Not sensitive to deck imperfections or altitude.

Some of the disadvantages of this system are:

(1) Requires engine bleed air or APU to inflate trunk.

(2) Platform size relatively large due to trunk size and suck in (approximately 15 ft^2 larger than comparable rigid skirt system at design suction force).

(3) Possibly require development of elastic trunk material to give desired stretch characteristics and wear characteristics (trunk will probably require wear strip at ground tangent).

(4) Due to small size of trunk and the low pressures, it is possible that suction will be required to keep the deflated trunk against the platform when deflated (or actual stowage in a cavity) because of the low tension in the material.

(5) Possible problems maintaining trunk at proper height to prevent loss of ground contact or trunk flattening against the deck. Possibly require height gage or pressure sensors.

(6) Possible relatively high translation forces.

(7) Study required to determine optimum trunk size.

Rigid Skirt System – This system is very similar to the Elastic Trunk System. The basic difference is in the manner in which the air cushion is formed. A rigid fiberglass skirt replaces the elastic trunk (Figure 13). A soft rubber seal (possibly pneumatic) is attached to the lower surface of the skirt at the ground tangent line. This seal serves to prevent damage to the skirt and to prevent air flow under the skirt. The skirt is free floating in relation to the platform. This is accomplished with pneumatic snubbers (two shown but four may prove desirable). The pneumatic snubbers also serve to lift the skirt to its maximum height, when the system is retracted, by reversing the pressure in the cylinder. A bellows seal, around the top of the skirt, is used to prevent air leakage into the cushion. The bellows seal may have to be reinforced radially to insure that it does not interfere with the free motion of the skirt. Vents in the skirt are provided as required to prevent fan stall. The actual size of the vent holes required could be determined by the amount of natural leakage under the skirt.

At ground impact, the skirt would compress the snubbers and the shock struts would absorb the impact loads. The cushion cavity would be partially evacuated during impact (relief valves may be required) as the platform approaches the deck. This assists the fan in rapidly creating the required hold-down force. As the landing gear oleos extend, after impact, the platform returns to its operating height. The platform height is not critical, as the pneumatic snubbers will keep the skirt in contact with the deck even if the platform height varies (within limits). The snubbers apply a small, constant, downward force on the skirt to maintain deck contact and seal. The translation force is then a function of this down load on the skirt and the coefficient of friction. Therefore, by preselecting the down load, the translation forces can be very small.

Some of the disadvantages of the Rigid Skirt System are:

(1) Possible damage to skirt at impact.

(2) Some development may be required for snubber/retract system.

(3) Some development may be required for the bellows seal.

Some of the advantages of the Rigid Skirt System are:

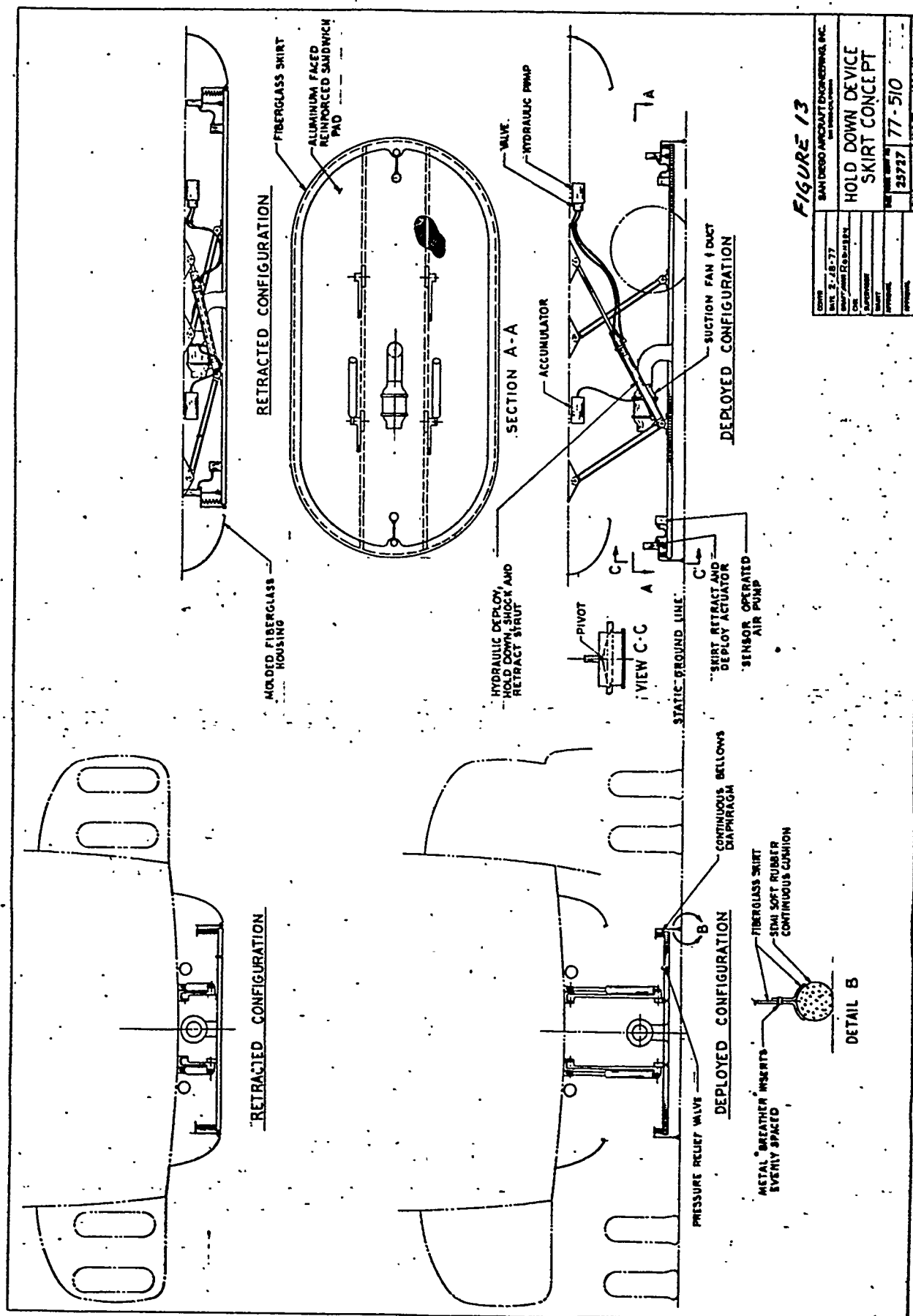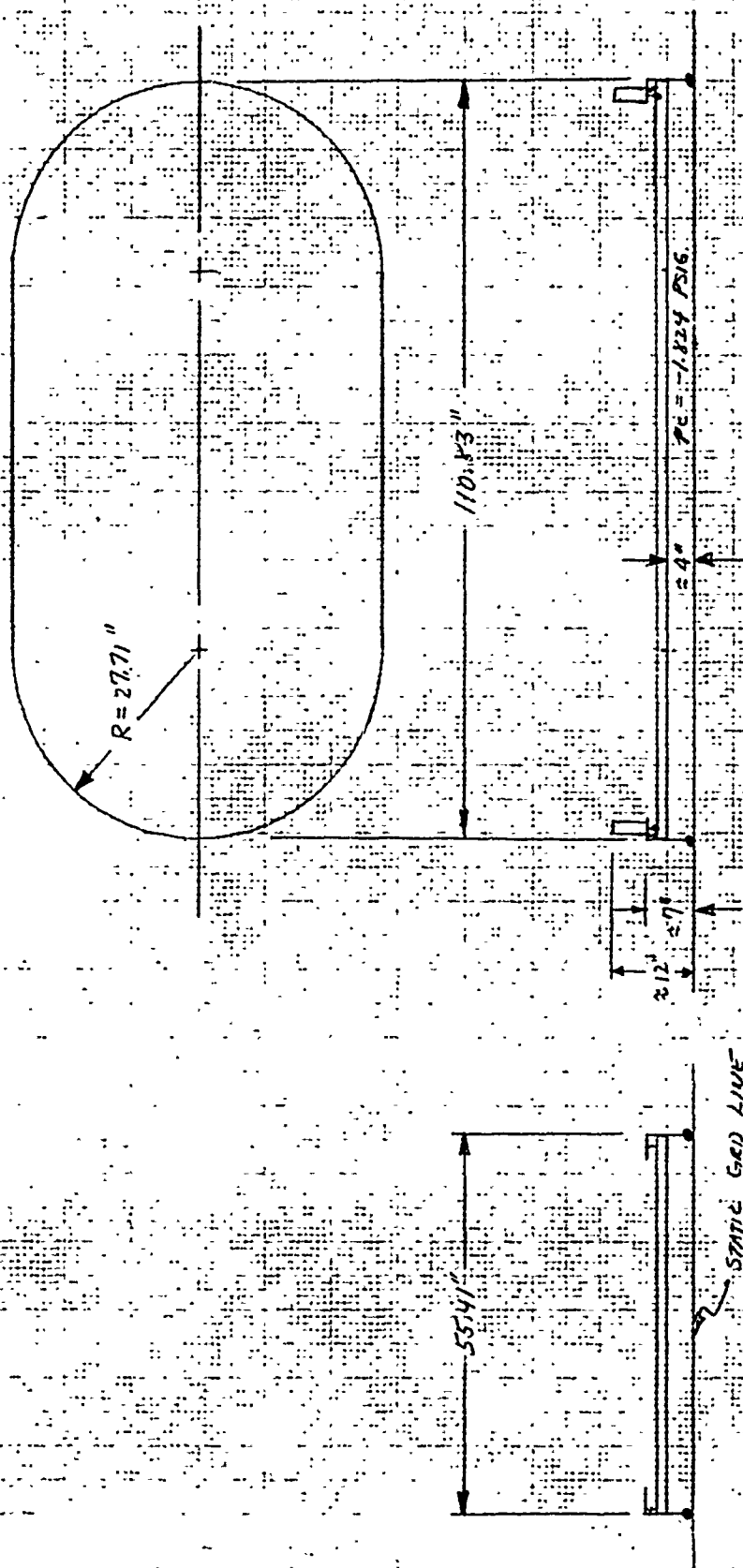(1) Relatively small platform required.

(2) Small, low-powered fans required.

RETRACTED CONFIGURATION

FIBERGLASS SKIRT

ALUMINUM FACED
REINFORCED SANDWICH
PAD

SECTION A-A

VALVE

HYDRAULIC PUMP

ACCUMULATOR

DEPLOYED CONFIGURATION

MOLDED FIBERGLASS
HOUSING

HYDRAULIC DEPLOY,
HOLD DOWN, SHOCK AND
RETRACT STRUT

PIVOT

VIEW C-C

STATIC GROUND LINE

SUCTION FAN & DUCT

SKIRT RETRACT AND
DEPLOY ACTUATOR

SENSOR OPERATED
AIR PUMP

RETRACTED CONFIGURATION

DEPLOYED CONFIGURATION

CONTINUOUS BELLOWS
DIAPHRAGM

FIBERGLASS SKIRT

SEMI SOFT RUBBER
CONTINUOUS CUSHION

PRESSURE RELIEF VALVE

METAL BREATHER INSERTS
EVENLY SPACED

DETAIL B

FIGURE 13

SAN DIEGO AIRCRAFT ENGINEERING, INC.

HOLD DOWN DEVICE
SKIRT CONCEPT

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FIGURE 14

BASE POINT RIGID SKIRT SYSTEM

$F_S = 10000$ LBS

AREA CUSHION $= 38.07$ FT²

$R = 27.71"$

$110.83"$

$\leq 4"$

$Pc = -1.824$ PSIG.

$\geq 12"$

$\leq 7"$

$55.41"$

STATIC GND LINE

(3) Very small technical risk.

(4) Simple design.

(5) No engine bleed air required.

(6) Low translation drag.

(7) Controlled cushion area as compared to Elastic Trunk System.

(8) Relatively easy stowage.

(9) Relatively small package and light weight.

As for the Elastic Trunk System, the Rigid Skirt System could be reduced in size if higher pressure ratio fans can be located. The cushion size is directly proportional to the cushion pressure. A trade-off would have to be conducted as to cushion size, fan weight and fan pressure ratio.

The dimensions of the base point Rigid Skirt System are shown in Figure 14. Of the three suction hold-down systems developed in this study, we believe the Rigid Skirt System to show the most promise. We recommend the Rigid Skirt System for further development.
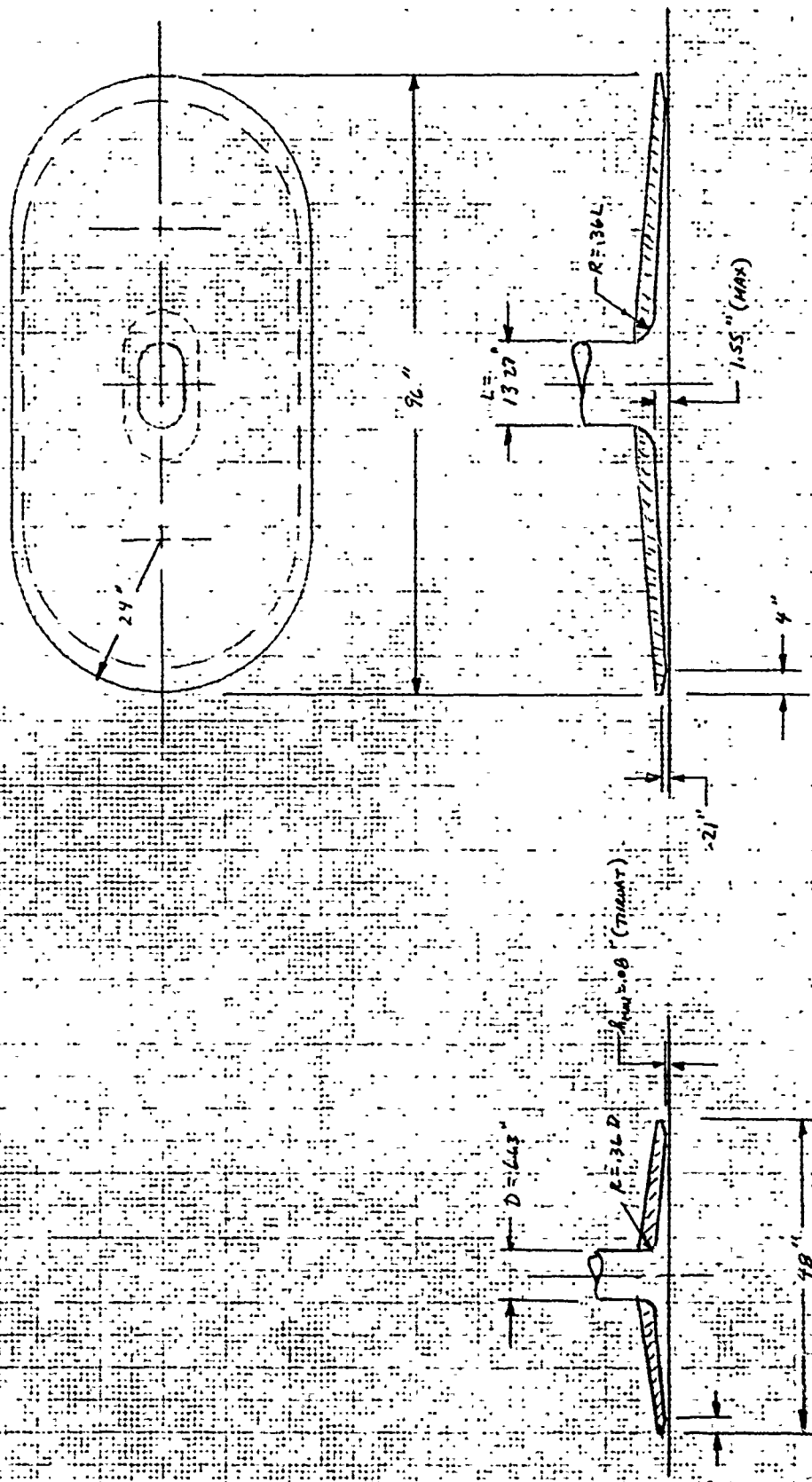
Bernoulli System — This system is based on the principle that total pressure remains constant in an enclosed system. That is, the summation of static pressure and velocity pressure is constant ($p_T = p_s + q = $ Constant). A large volume of low pressure air is blown under a honeycomb platform, at its center, through a radial diffusor. The diffusor is designed such that the exit area of the diffusor is equal to the inlet duct area. One side of the diffusor is provided by the duct. At the diffusor exit, the air flow is directed parallel to the deck. The bottom of the cushion platform is so shaped (concave) that the flow area is constantly decreasing as the air moves towards the outer edge of the pad. The minimum height of the pad (flow throat) is reached approximately two inches from the outer edge of the pad. The outer two inches serve as an expanding diffusor (flow area increases) to bring the static pressure under the pad back to ambient at the outer edge. The concave lower surface of the pad is shaped to permit a linear variation of static pressure from the inlet diffusor exit to the critical pressure at the throat. As the flow area decreases, the velocity of flow increases, therefore increasing velocity pressure. As the velocity pressure increases, the static pressure decreases. The difference between ambient pressure and the static pressure under the pad results in a downward force on the upper side of the pad.

The critical pressure ratio for air is approximately 0.53. That is the static pressure at the throat is 53% of the total pressure. For this design, the fan must deliver a total pressure of 15.14 psia to the diffusor; therefore, at the throat the static pressure under the pad is 8 psia. At the throat, the difference between static pressure and ambient pressure is -6.7 psi. At the exit of the

RETRACTED CONFIGURATION

RETRACTED CONFIGURATION

RETRACTABLE DOORS
IN HOUSING

FIBERGLASS BELLMOUTH

FIBERGLASS/ALUMINUM
COMPOSITE SANDWICH
PAD

DIFFUSER
OUTLET

YOKE

SECT A-A

ACCUMULATOR

HYDRAULIC DEPLOY
HOLD DOWN SHOCK
AND RETRACT STRUT

VALVE

HYDRAULIC PUMP

1A

A

FAN

FLEX DUCT

FIBERGLASS
HOUSING

DEPLOYED CONFIGURATION

MAX COMPRESSED COND

FLAT TIRE COND

STATIC GROUND LINE

SUSPENSION YOKE

DEPLOYED CONFIGURATION

FIGURE 15

SAN DIEGO AIRCRAFT ENGINEERING, INC.

HOLD DOWN DEVICE
BERNOULLI PAD CONCEPT

DATE 3/2/77

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FIGURE 16

BASE POINT BERNOULLI SYSTEM

$F_S = 10000$ LBS
AREA CUSHION = 28.57 FT²

inlet diffusor, the static pressure under the pad is approximately + .26 psi greater than ambient. By integrating the pressure differential over the pad area and applying an efficiency factor of approximately 70%, the suction hold-down force is obtained.

The minimum height of the pad (at the throat) is approximately .08 inches. This height can be increased by increasing the air flow of the fan. The dimensions of the pad (base point Bernoulli System) are given in Figure 16.

For the Bernoulli System, the cushion pad is mounted on the trapeze, retract/ deployment system by means of a pivoted yoke. The yoke will permit the pad to position itself parallel to the deck, thus creating the required air bearing gap at the exit diffusor throat. An upward force (lift) will be applied by the trapeze hydraulic cylinders. This will tend to pull the aircraft downwards, increasing the load on the main landing gear.

The maximum down position of the pad is approximately equal to the static ground line of the aircraft. Therefore, the pad will not contact the deck until the landing impact loads are essentially absorbed by the main landing gear. It is anticipated that an air cushion will build up under the pad to help cushion the pad at deck contact. The shock struts will also help absorb any landing loads on the pad. It may be required to add a "tail skid" type bumper off the pad trailing edges for nose high landings.

Some disadvantages of the Bernoulli System are:

(1) Possibly high development risk.

(2) Possible damage during impact.

(3) Possible problems in maintaining suction force. Requires proper relationship between pad and deck.

(4) High air flow required, resulting in relatively large fan and high power requirements.

(5) Relatively large housing due to fan size and inlet diffusor.

Some advantages of the Bernoulli System are:

(1) Lightest overall system weight.

(2) Small air cushion pad.

(3) If the fan can be mounted internal to the aircraft mold lines, the overall external housing can be made relatively small.
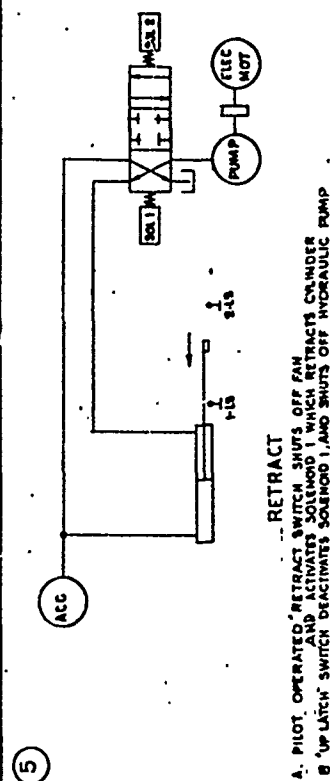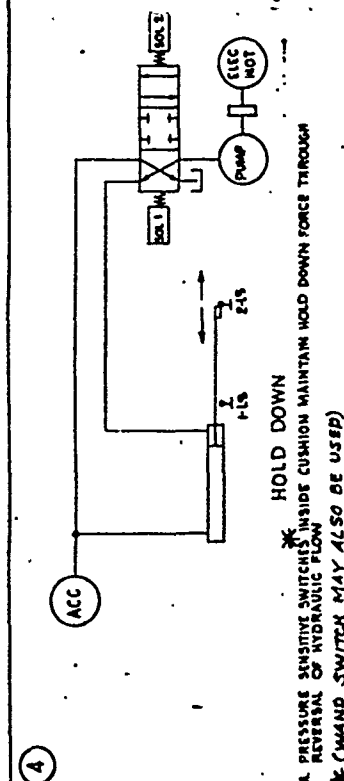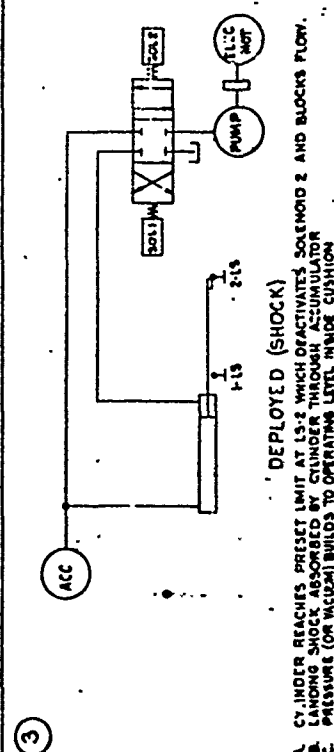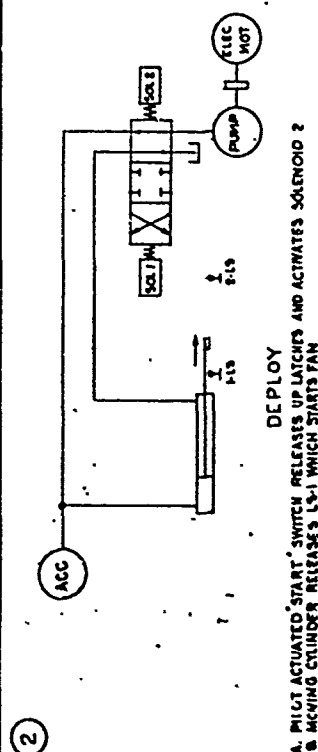
(4) Low translation force.

FIGURE 17

(1) RETRACTED AND NON FUNCTIONING

(2) DEPLOY

A. PILOT ACTUATED START SWITCH RELEASES UP LATCHES AND ACTIVATES SOLENOID 2
B. MOVING CYLINDER RELEASES LS-1 WHICH STARTS FAN

(3) DEPLOYED (SHOCK)

A. CYLINDER REACHES PRESET LIMIT AT LS-2 WHICH DEACTIVATES SOLENOID 2 AND BLOCKS FLOW.
B. LANDING SHOCK ABSORBED BY CYLINDER THROUGH ACCUMULATOR
C. PRESSURE (OR VACUUM) BUILDS TO OPERATING LEVEL INSIDE CUSHION

(4) HOLD DOWN

A. PRESSURE SENSITIVE SWITCHES INSIDE CUSHION MAINTAIN HOLD DOWN FORCE THROUGH REVERSAL OF HYDRAULIC FLOW.
✱ (WAND SWITCH MAY ALSO BE USED)

(5) RETRACT

A. PILOT OPERATED RETRACT SWITCH SHUTS OFF FAN AND ACTIVATES SOLENOID 1 WHICH RETRACTS CYLINDER
B. UP LATCH SWITCH DEACTIVATES SOLENOID 1, AND SHUTS OFF HYDRAULIC PUMP

Panel labels: ACC, SOL.1, SOL.2, PUMP, ELEC MOT, LS-1, LS-2

Title block:
SAN DIEGO AIRCRAFT ENGINEERING, INC.
HOLD DOWN DEVICE
SYSTEM ACTUATION
DATE 3-7-77
DRAFTSMAN Roberts
25727   7?-513

WEIGHT BASIS

A brief outline of the basis used for estimating the system weights is presented below.

Pad

The pad was assumed to be of 1.5 inch thick aluminum honeycomb construction. The outer skins are 0.02 inch thick, and the core is assumed to weigh three pounds per cubic foot. Therefore, the total weight per square foot of pad is .951 pounds. This weight was increased 60% (80% for Bernoulli System) to account for stiffeners and edge finish.

$$(W)_{Pad} = 1.522 \, A_p \text{ Lbs/Ft}^2 \text{ (Elastic Trunk and Rigid Skirt Systems)}$$

$$(W)_{Pad} = 1.826 \, A_p \text{ Lbs/Ft}^2 \text{ (Bernoulli System)}$$

where A_p = Area of the pad (ft^2)

Retraction/Deployment System

Material = aluminum struts, cylinders and fittings.

Struts (4)	= .000731 F_s	(Lbs)
Hydraulic Cylinders (2)	= .001200 F_s	(Lbs)
Hydraulic Fluid	= .000442 F_s	(Lbs)
*Miscellaneous	= 24	(Lbs)
Fittings	= 12	(Lbs)

$$W = .0024 \, F_s + 36 \text{ (Lbs)}$$

*Includes latches, tubing accumulators, and pump, plus 25% installation.

Elastic Trunk and Attachments

Material = rubber/nylon with aluminum attachments.

Elastic Material	= .1573 $(F_s)^{.5}$	(Lbs)
Attachments	= .1653 $(F_s)^{.5}$ + .86	(Lbs)

$$W = .3226 \, (F_s)^{.5} + .86 \text{ (Lbs)}$$

Yoke (Bernoulli System)

Material = aluminum channel

$$W = 4 \text{ (Lbs)}$$

Duct   (Bernoulli System)

   Material = wire reinforced rubber/nylon

$$W = 2.992 + .000141 \, F_s \qquad \text{(Lbs)}$$

Bellows Seal (Rigid Skirt System)

   Material = nylon reinforced rubber

$$W = .0803 \, (F_s)^{.5} \qquad \text{(Lbs)}$$

Fairing and Attachments

   Material = .06 inch thick fiberglass

$$W = .753 \, (S)_{wet} \qquad \text{(Lbs)}$$

$(S)_{wet} = 78.8 + 1.89 \, (A_p - 28.57) \quad = \text{Elastic Trunk \& Rigid Skirt}$

$(S)_{wet} = 88.8 + 2.04 \, (A_p - 28.57) \quad = \text{Bernoulli System .}$

Where $A_p \quad = \quad$ Pad area (ft^2)

   $S_{wet} \quad = \quad$ Wetted area of fairing (ft^2)

   Note: 30% has been added for stiffeners and fasteners.

Rigid Skirt and Attachment

The skirt is constructed of a foam filled fiberglass shell. The foam core weighs 4 lbs/ft^3 and the skins are 0.05 inch thick. The shell is 0.5 inch thick. A soft rubber seal is attached to the bottom of the skirt around its periphery. The skirt weight was calculated to be 1.3 lbs/ft.

$$W = .309 \, (F_s)^{.5} + 8 \qquad \text{(Lbs)}$$

Fans (Rigid Skirt and Elastic Trunk Systems)

$$W = .153 \, (F_s)^{.5} \qquad \text{(Lbs)}$$

The fan weight has been increased 25% to account for installation.

Fan (Bernoulli System)

$$W = 25.23 + .001187 \, F_s \quad \text{(Lbs)}$$

The fan weight has been increased 40% to account for installation.

By collecting all the above terms and expressing the platform area (A_p) as a function of suction force (F_s), the following equations are derived for the system weights:

Elastic Trunk System

$$W = 58.60 + .8777 \, (F_s)^{.5} + .01361 \, F_s \qquad \text{(Lbs)}$$

Rigid Skirt System

$$W = 62.68 + .5423 \, (F_s)^{.5} + .01361 \, F_s \qquad \text{(Lbs)}$$

Bernoulli System

$$W = 113.85 + .01107 \, F_s \qquad \text{(Lbs)}$$

The estimated weight for the three base point designs are given in Figure 18. The effect of suction hold-down force on system weight is presented in the following section (Figure 19).

SANDAIRE

FIGURE 18

BASE POINT DESIGN = ESTIMATED WEIGHT

$$F_s/W \quad = \quad 0.5$$

$$W \quad = \quad 20,000 \text{ lbs}$$

$$F_s \quad = \quad 10,000 \text{ lbs}$$

	Elastic Trunk System	Rigid Skirt System	Bernoulli System
Pad	80.31	57.94	52.18
Actuation System	60.00	60.00	60.00
Trunk and Attachments	33.10	–	–
Skirt and Attachments	–	38.87	–
Fairing and Attachments	93.77	72.87	66.87
Installed Fan (AMD)	15.30	15.30	37.10
Bellows Seal	–	8.03	–
Yoke	–	–	4.00
Ducting (Fan)	–	–	4.40
Total System Wt (W_{Syst})	282.48	253.00	224.55
W_{Syst}/W	.0141	.0127	.0112

PERFORMANCE AND SENSITIVITY STUDIES

The effect of suction hold-down force on system weight, cushion size, cushion pressure, fan power required, airflow and drag is shown in this section.

The weight of the three systems studied is shown in Figure 19 as a function of suction hold-down force.

The size of the cushion pad, including pad area, pad width and pad length is given in Figures 20, 21, and 22 as a function of suction hold-down force. Cushion pressure is shown in Figure 23.

The power required by the fans (AMD) for each of the three systems is presented in Figures 24 and 25. This data is shown for both BHP and Watts as a function of suction hold-down force. The design airflow is given in Figure 26.

Translation force is presented in Figure 27 as a function of suction hold-down force. This data is only a very crude approximation.

The translation drag of the Elastic Trunk System is a function of the trunk reaction against the deck (flattening) and the braking coefficient of friction. For rubber material (rubbing strip) at the ground tangent, the braking coefficient can be as high as .8 on a dry deck. However, with a teflon rubbing strip, the braking coefficient will be approximately .05. For purposes of this study, we have assumed a teflon rubbing strip with the trunk flattened 1.0 inch wide against the deck.

For the Rigid Skirt System, it has been assumed that the skirt reaction against the deck is three (3) times the weight of the skirt. In addition, it is assumed that the rubber seal on the bottom of the skirt has a teflon rubbing strip on the lower surface.

For the Bernoulli System, the theoretical translation force is zero (0) due to the air flow under the pad (air bearing).

Miscellaneous data has been included (Figures 28 through 32) for general information.

FIGURE 19

EFFECT OF SUCTION HOLD DOWN
FORCE ON SYSTEM WEIGHT

Figure axes: System Weight ~ LBS (vertical, 0 to 500) vs Suction Hold Down Force ~ 1000 LBS (horizontal, 0 to 24). Curves labeled: ELASTIC TRUNK, RIGID SKIRT, BERNOULLI SYST.
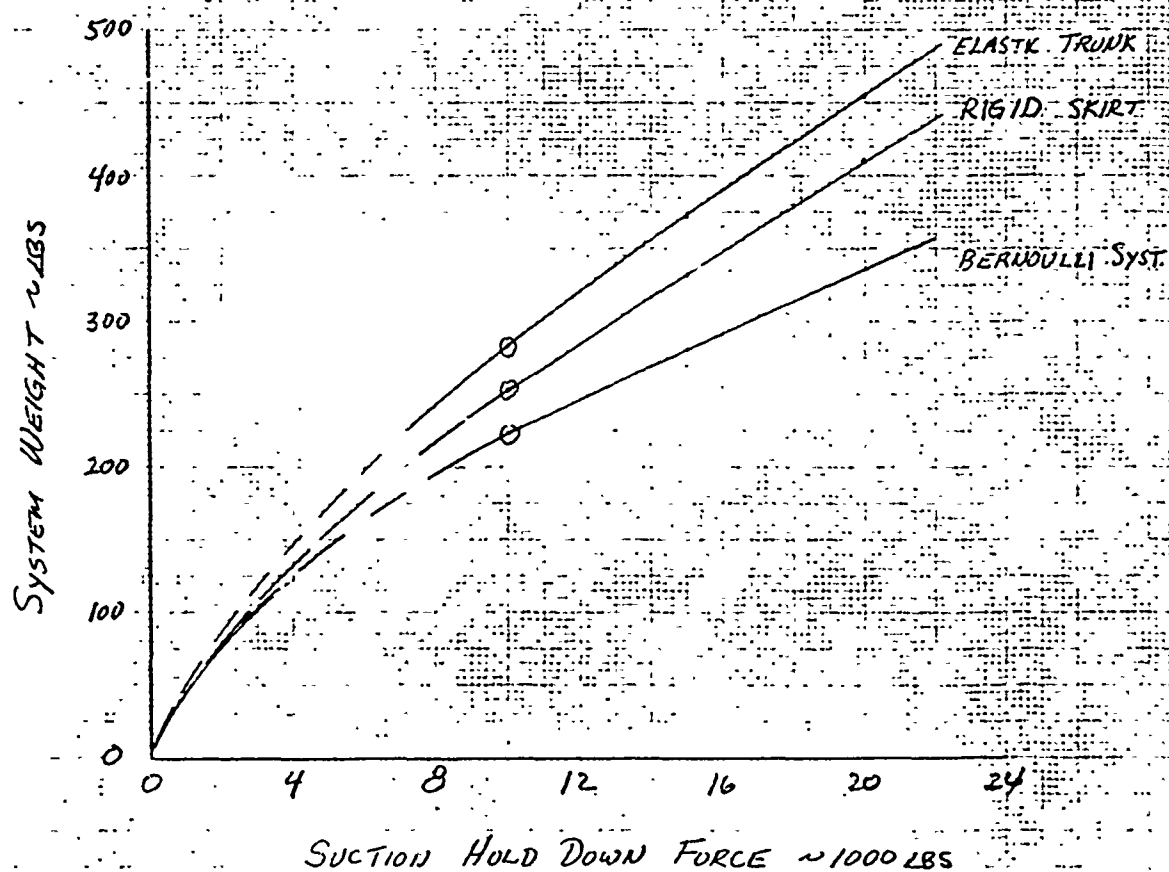
FIGURE 20

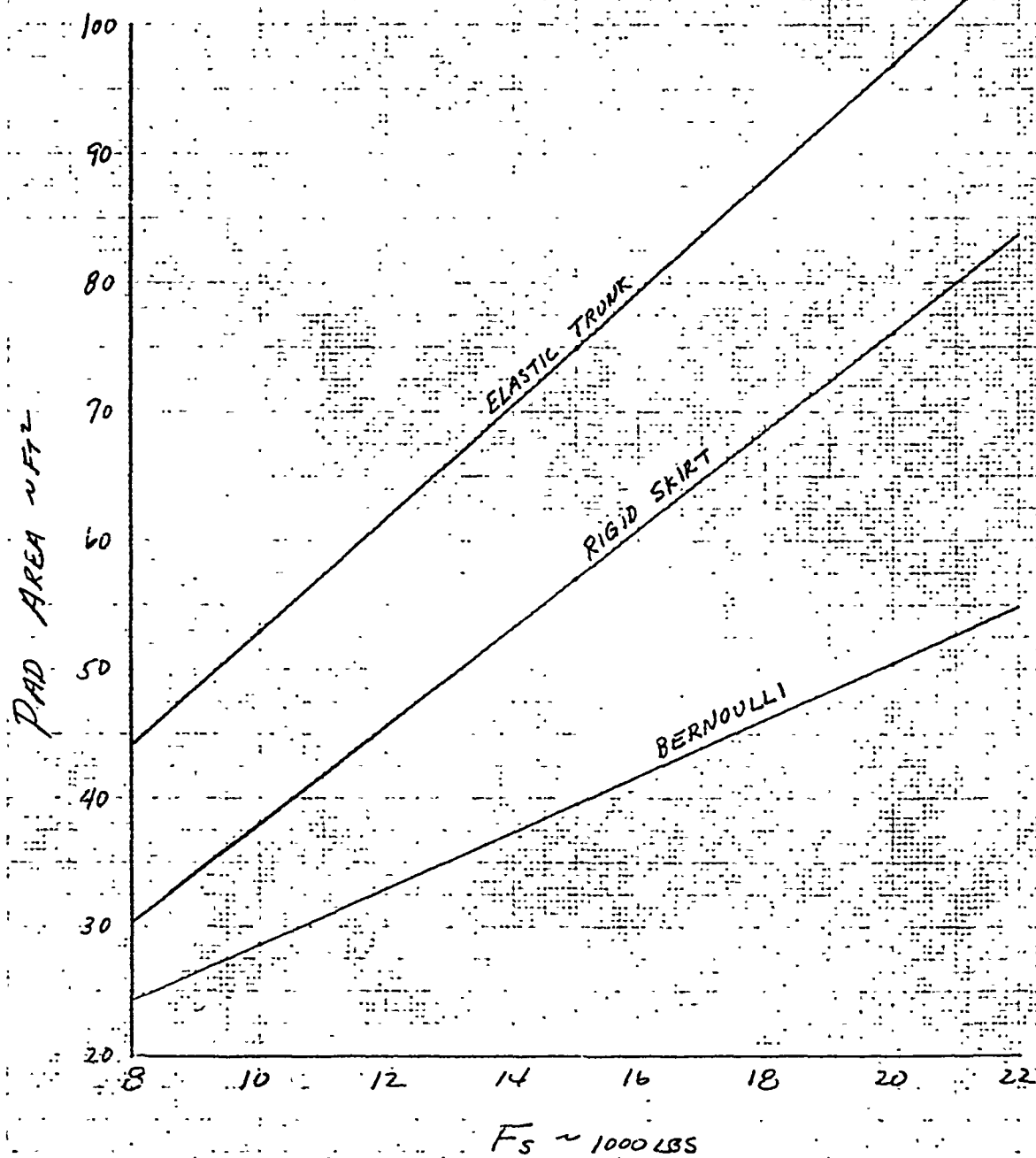EFFECT OF SUCTION HOLD DOWN
FORCE ON CUSHION PAD AREA

FIGURE 21

EFFECT OF SUCTION HOLD DOWN FORCE ON PAD WIDTH

FIGURE 22

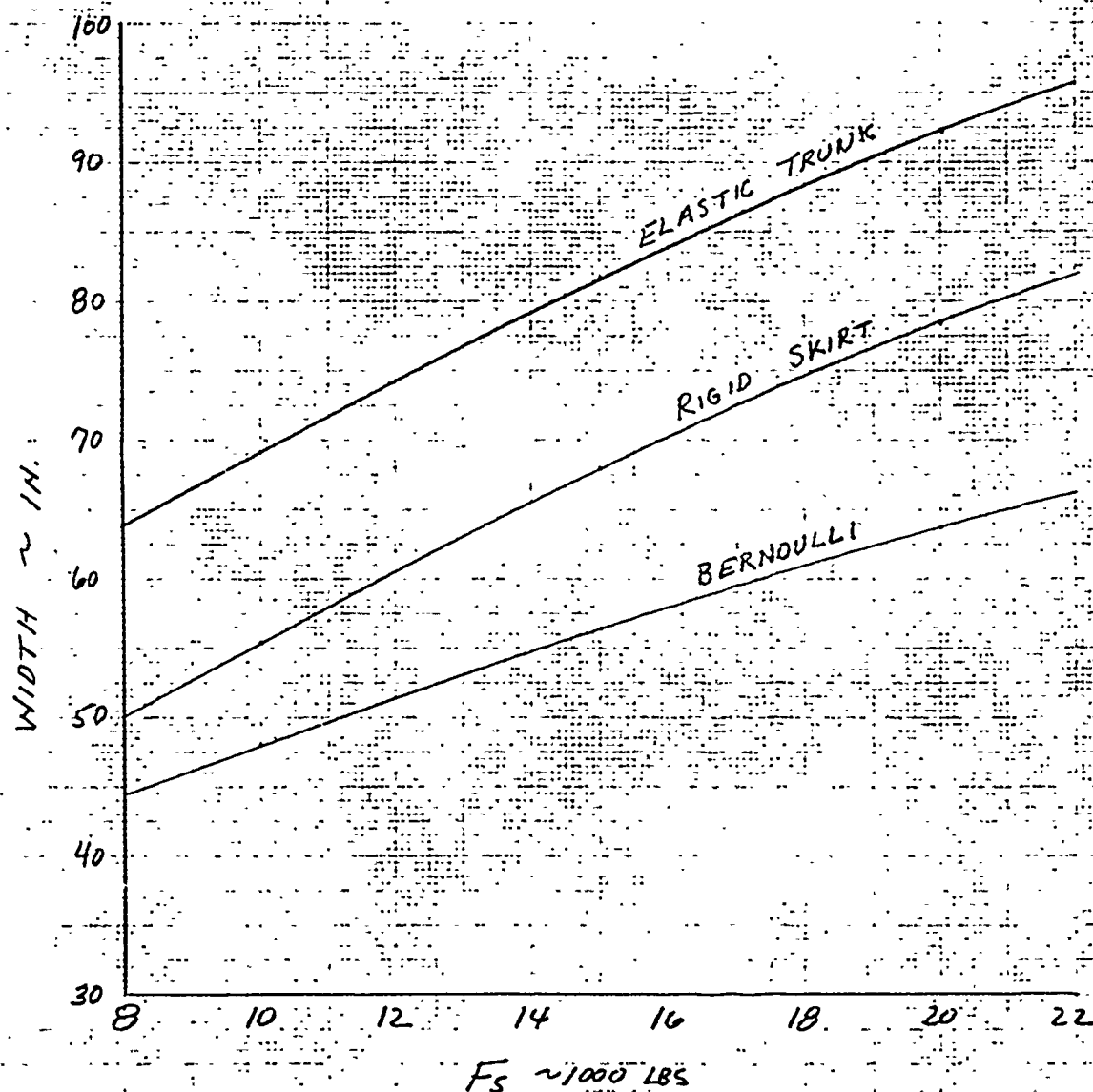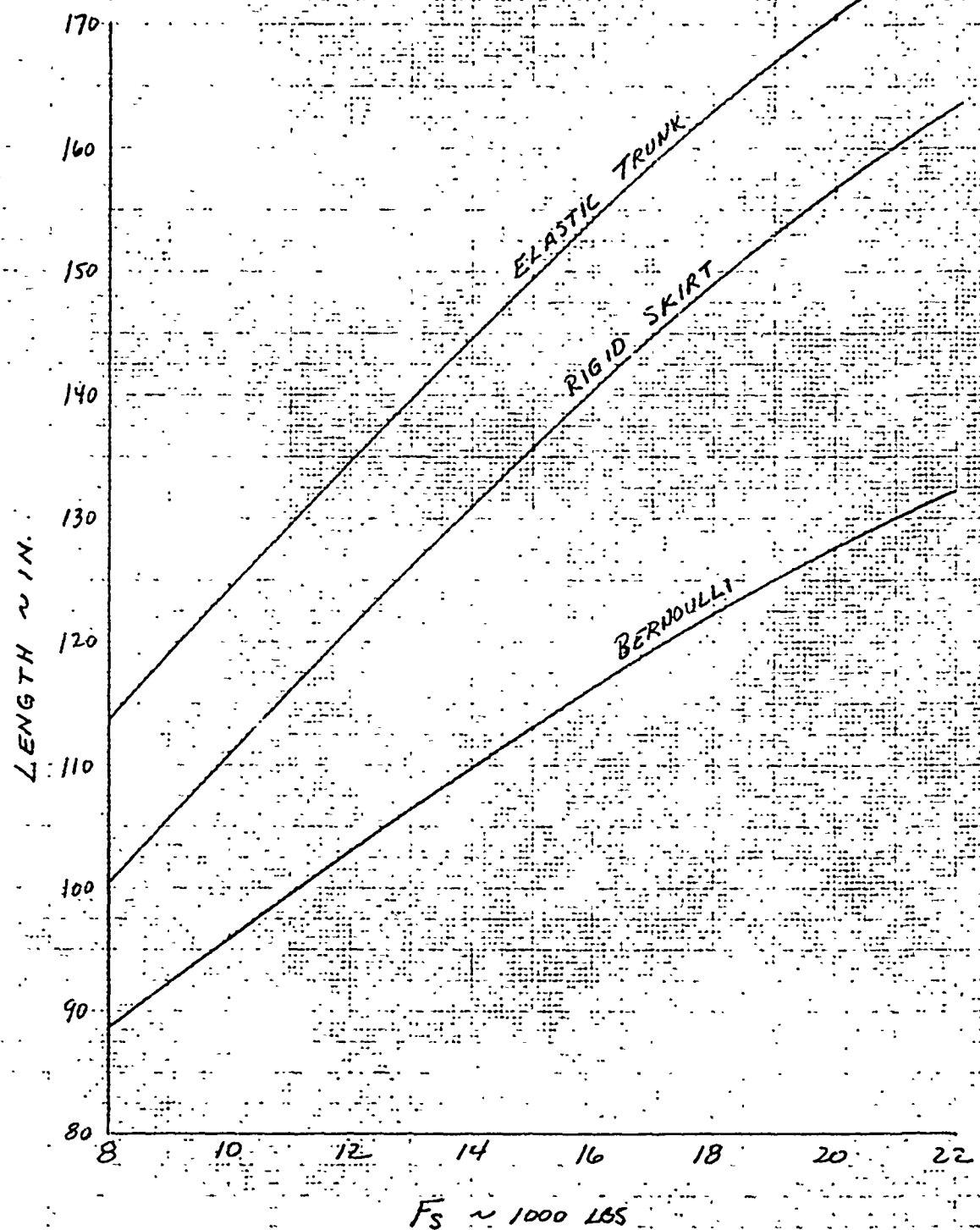EFFECT OF SUCTION HOLD DOWN
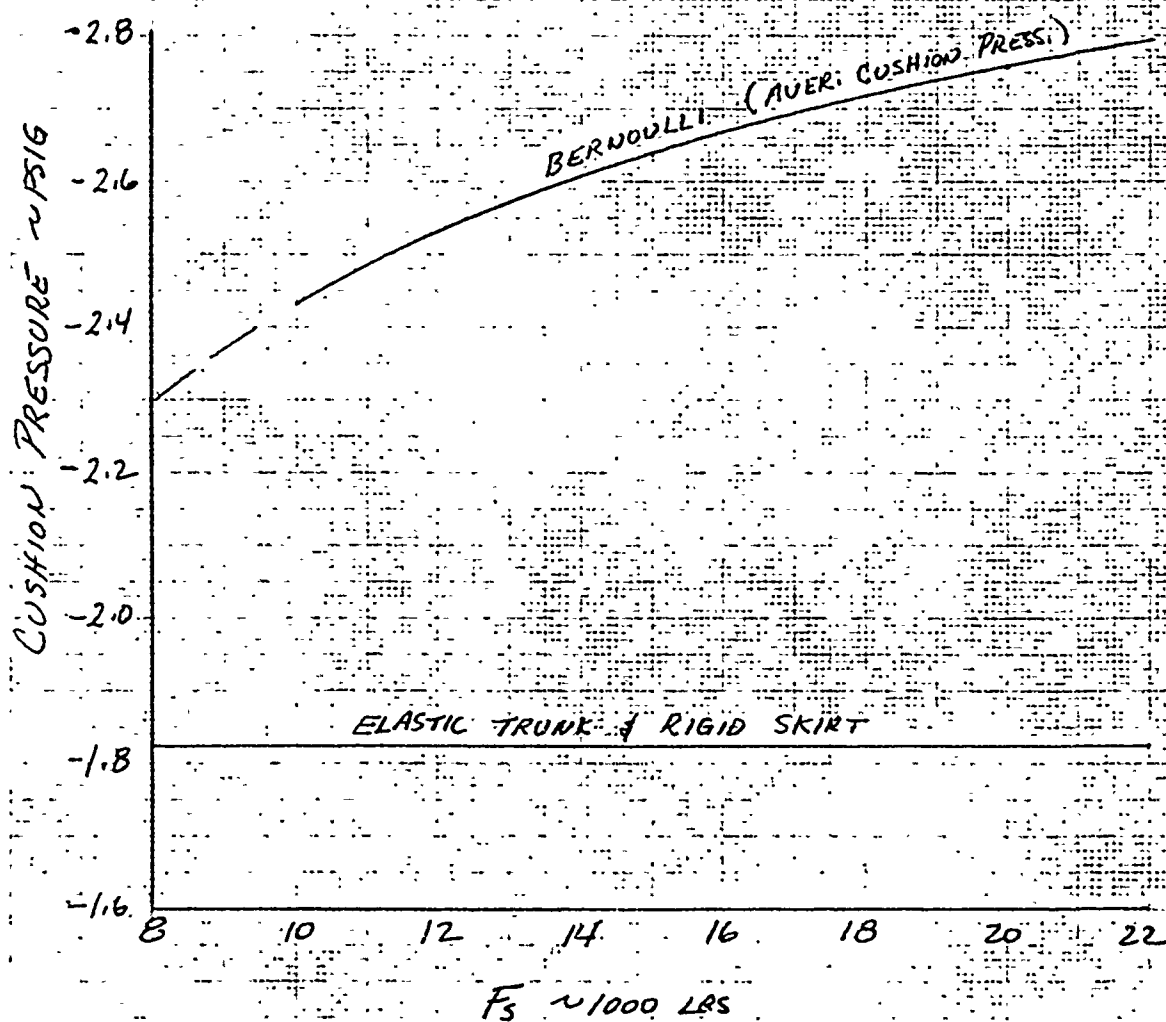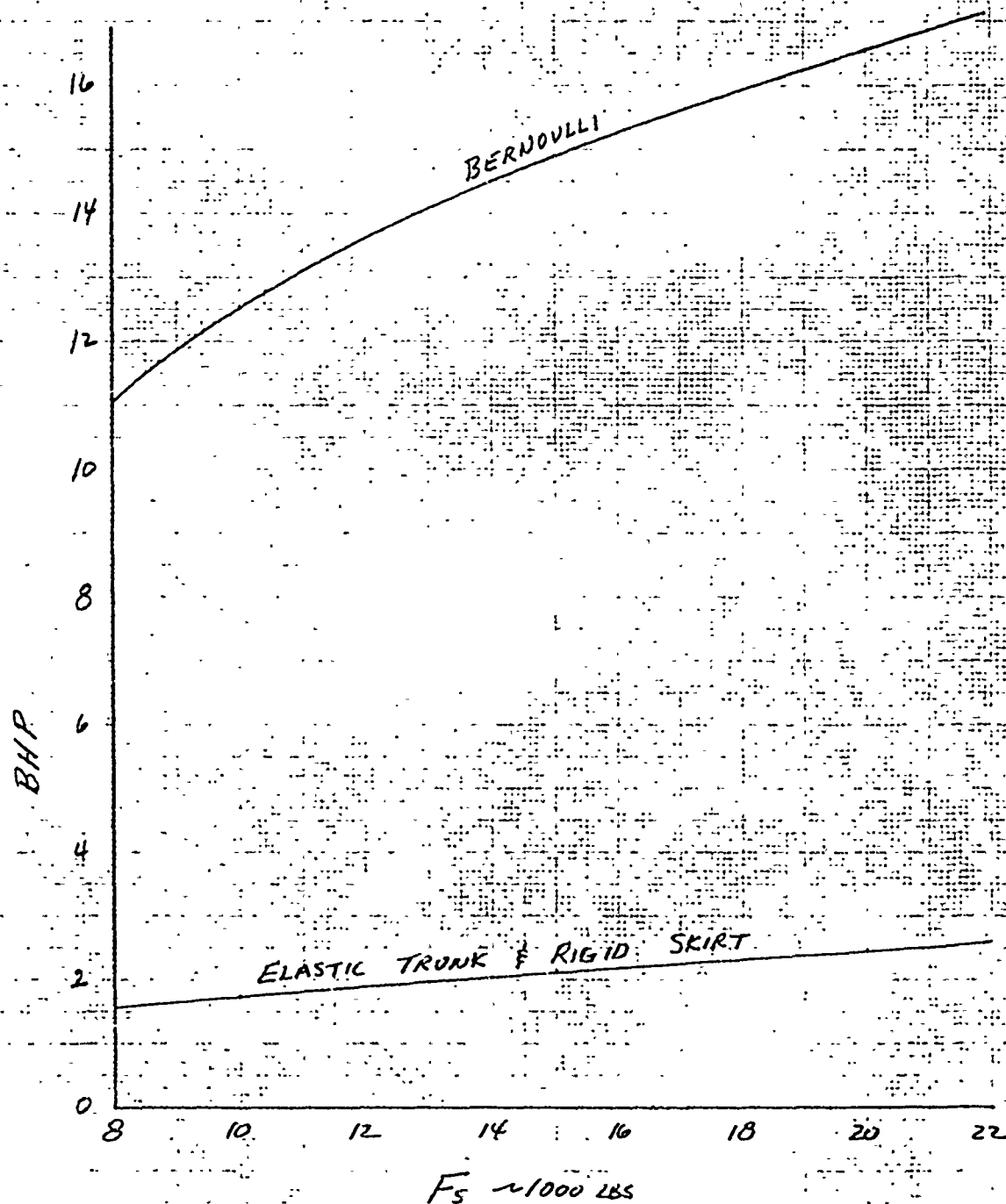FORCE ON LENGTH OF PAD.

FIGURE 23

EFFECT OF SUCTION HOLD DOWN
FORCE ON CUSHION PRESSURE

FIGURE 24

EFFECT OF SUCTION HOLD DOWN
FORCE ON POWER REQUIRED

(FAN POWER)
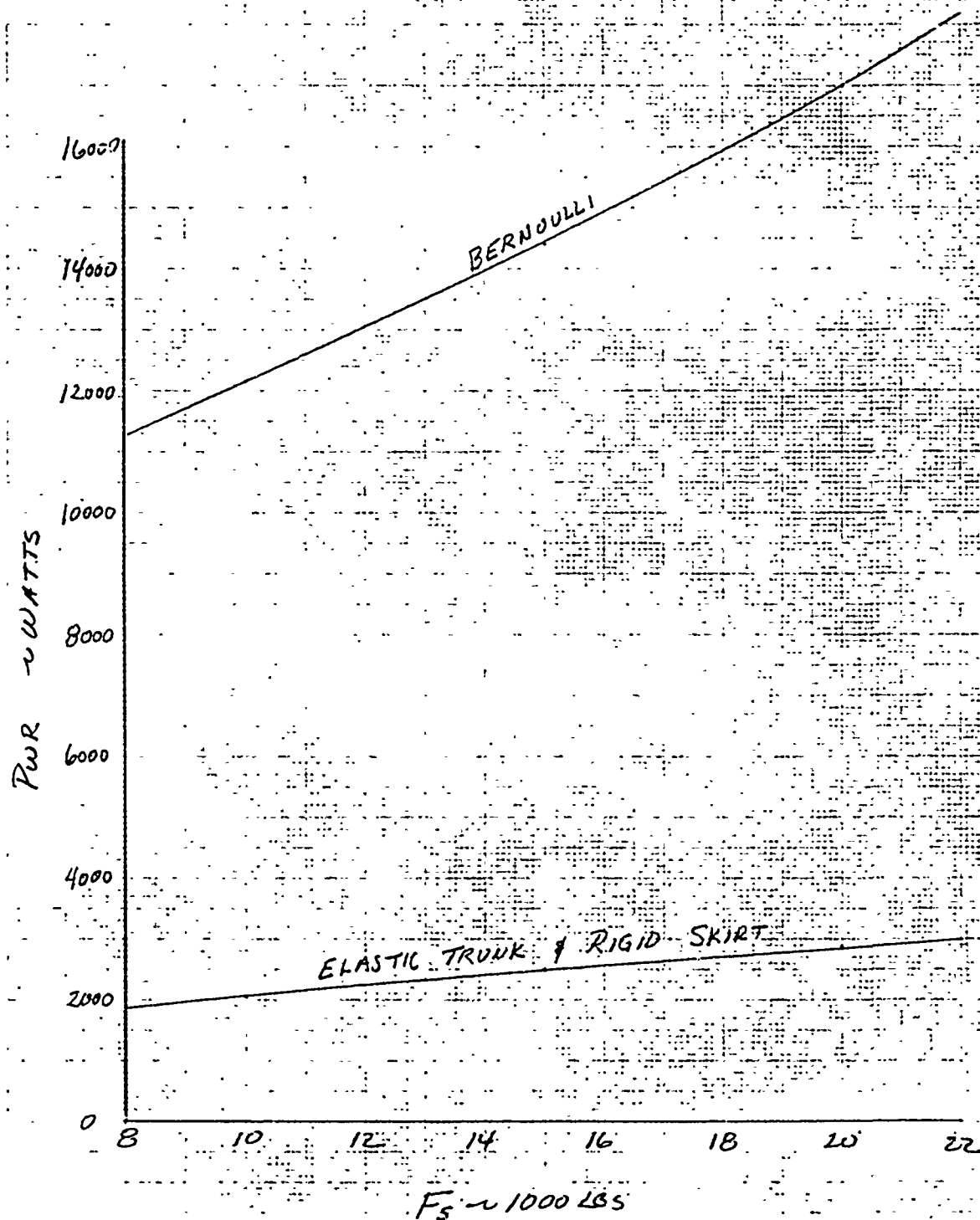
FIGURE 25

EFFECT OF SUCTION HOLD DOWN

FORCE ON BRAKE HORSE POWER

(FAN PWR)
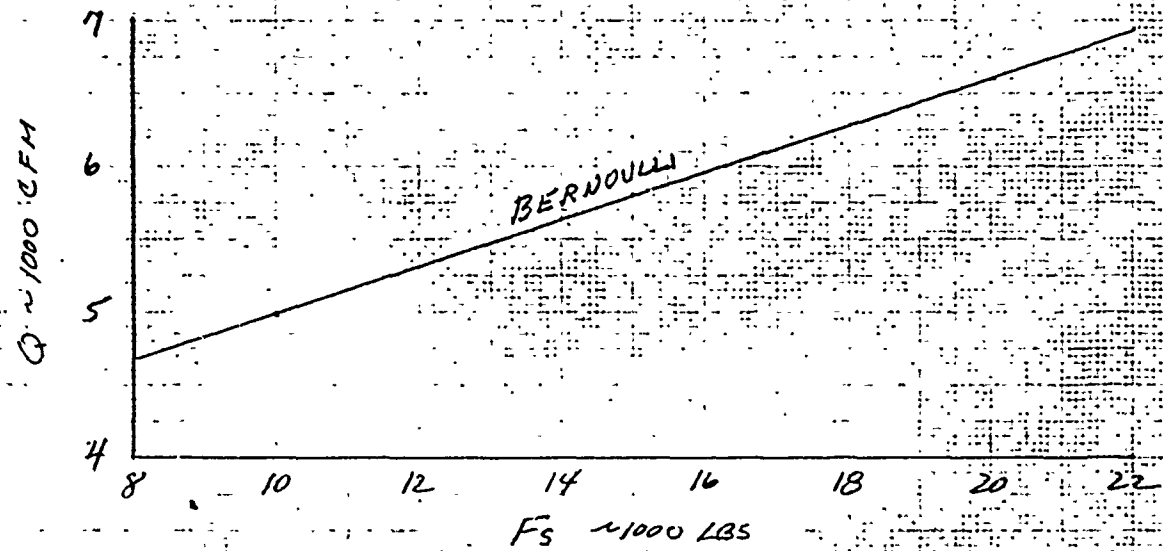
FIGURE 26

EFFECT OF SUCTION HOLD DOWN
FORCE ON AIR FLOW
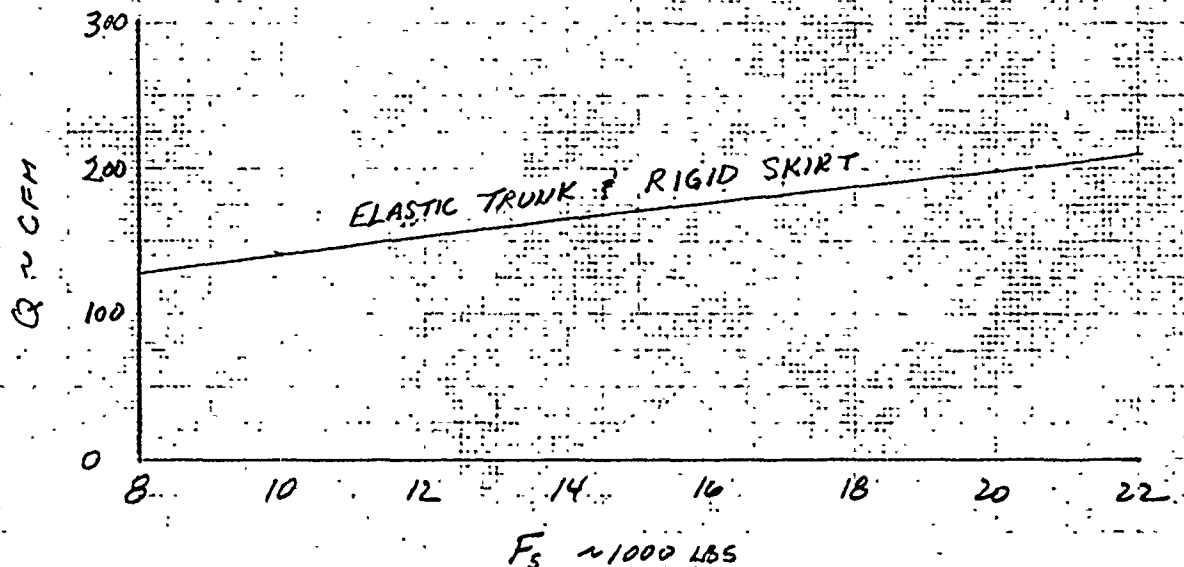
FIGURE 27

EFFECT OF SUCTION HOLD DOWN
FORCE ON TRANSLATION DRAG
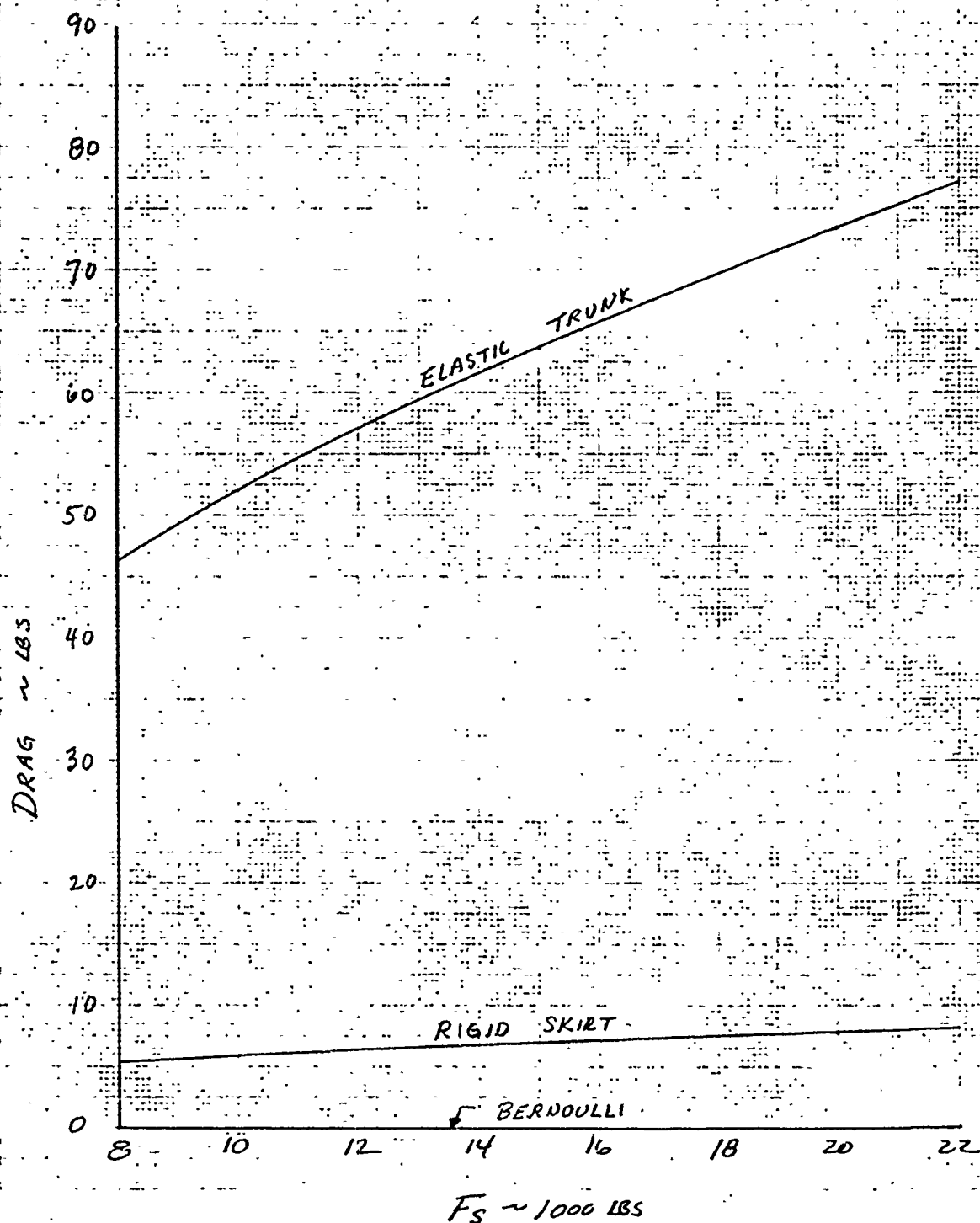
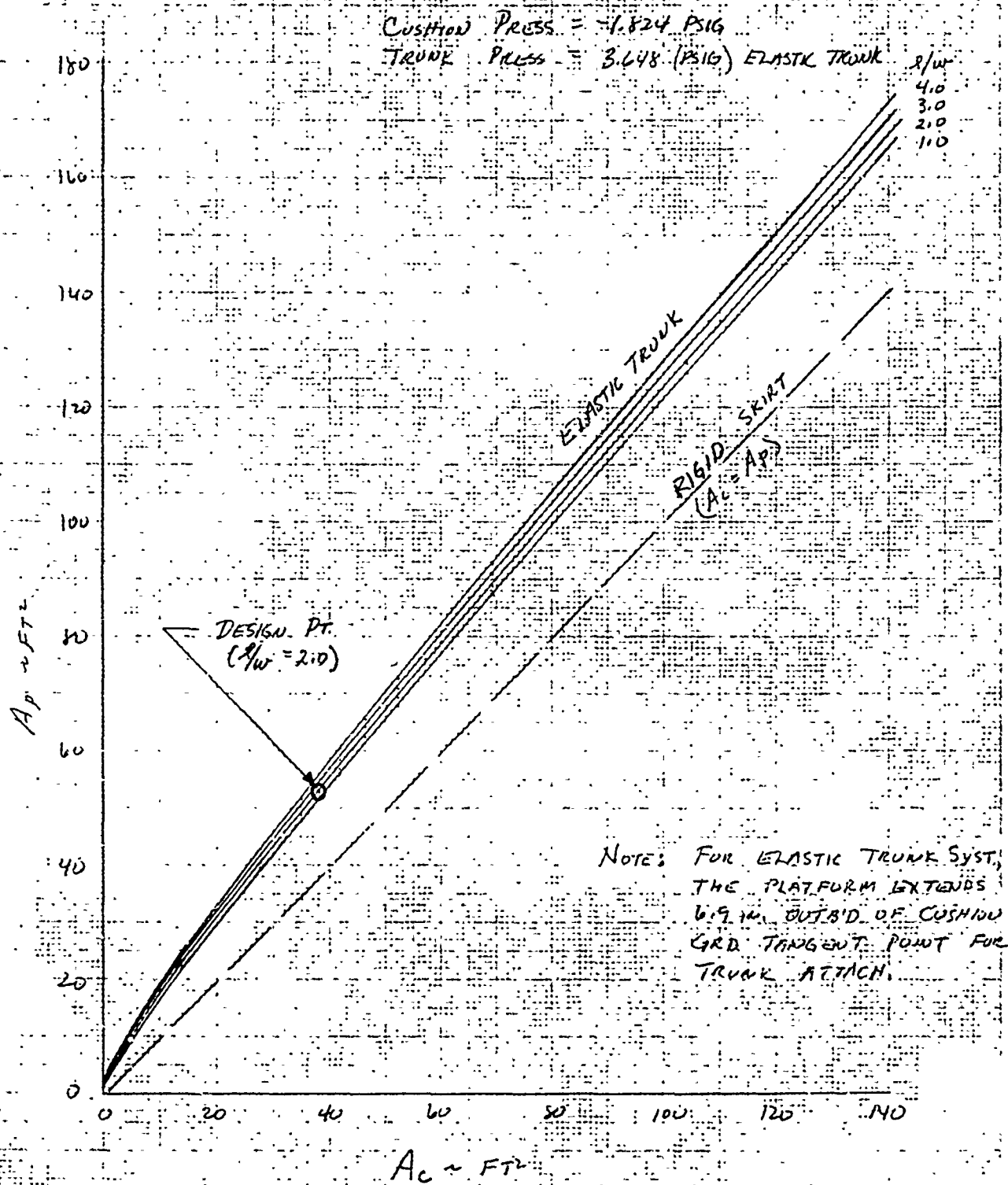FIGURE 28
EFFECT OF TRUNK LENGTH/
WIDTH RATIO ON PLATFORM
AREA.

CUSHION PRESS = 1.824 PSIG
TRUNK PRESS = 3.648 (PSIG) ELASTIC TRUNK

ℓ/w
4.0
3.0
2.0
1.0

ELASTIC TRUNK

RIGID SKIRT
($A_c = A_p$)

DESIGN PT.
($\ell/w = 2.0$)

NOTE: FOR ELASTIC TRUNK SYST,
THE PLATFORM EXTENDS
6.9 IN. OUTB'D OF CUSHION
GRD. TANGENT POINT FOR
TRUNK ATTACH.

$A_p \sim FT^2$

$A_c \sim FT^2$

FIGURE 29
EFFECT OF SUCTION FORCE, CUSHION PRESSURE, AND LENGTH/WIDTH RATIO ON CUSHION AREA, WIDTH AND CIRCUMFERENCE

DESIGN P_i
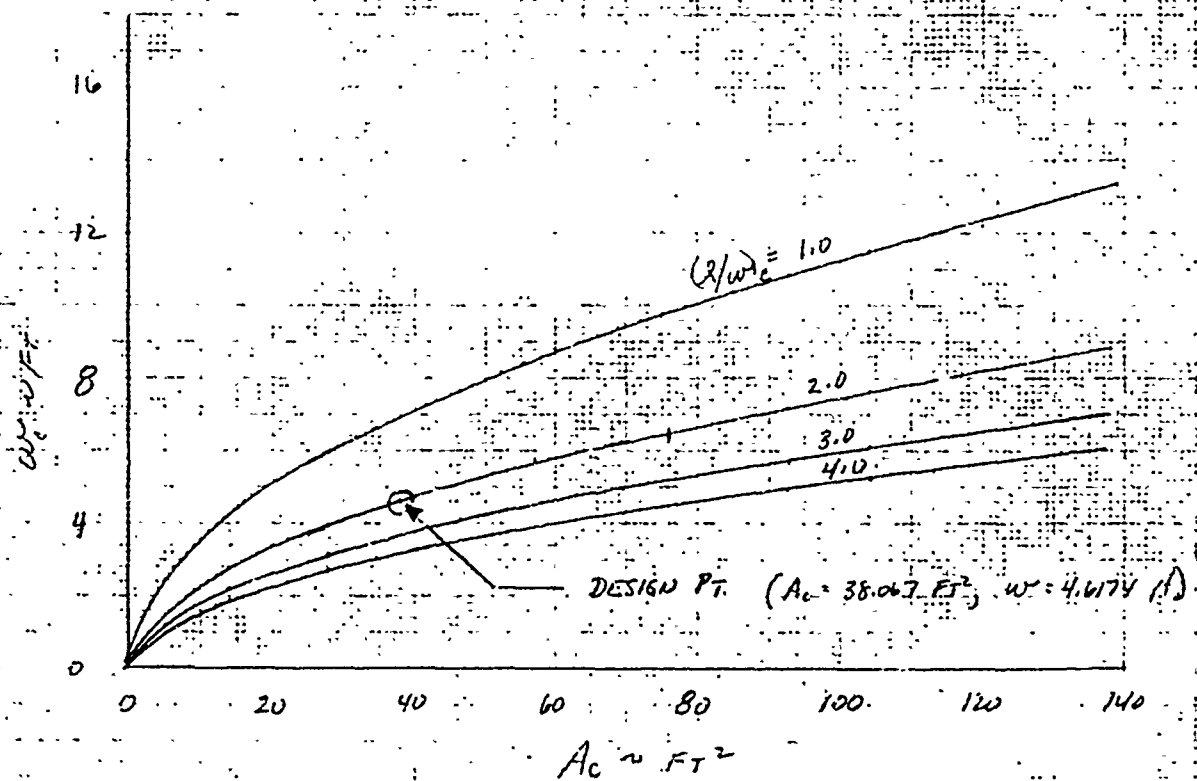$(A_c = 38.067 \text{ ft}^2$
$\ell = 18.47 \text{ ft}$
$c = 23.7413 \text{ ft})$

$A_c \sim$ CUSHION AREA
$c \sim$ CUSHION CIRCUM.
$F_s \sim$ SUCTION FORCE
$\ell \sim$ CUSHION LENGTH
$P_c \sim$ CUSHION PRESS.
$R \sim$ RADIUS
$w \sim$ CUSHION WIDTH
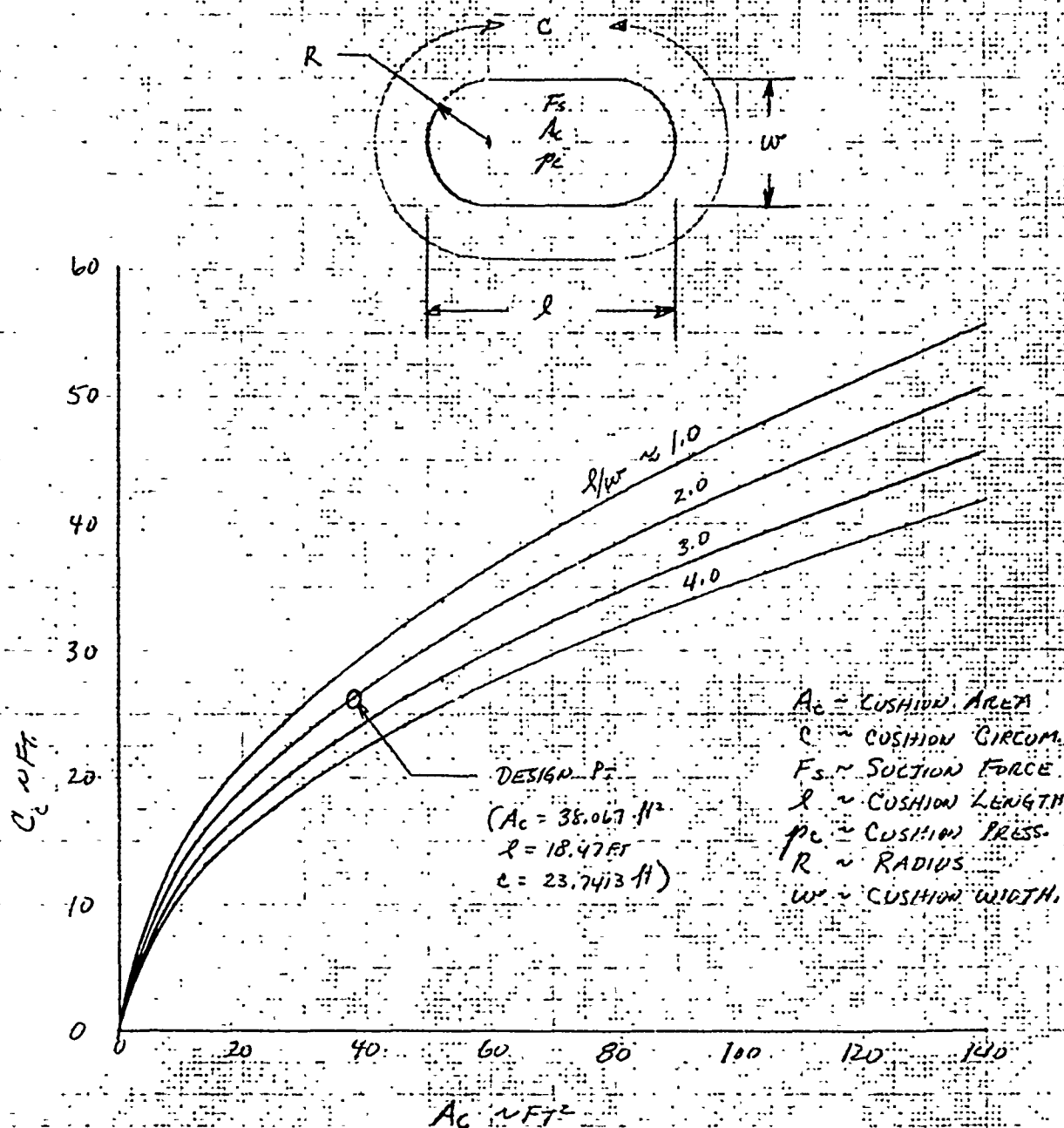
FIGURE 30
EFFECT OF SUCTION FORCE, CUSHION
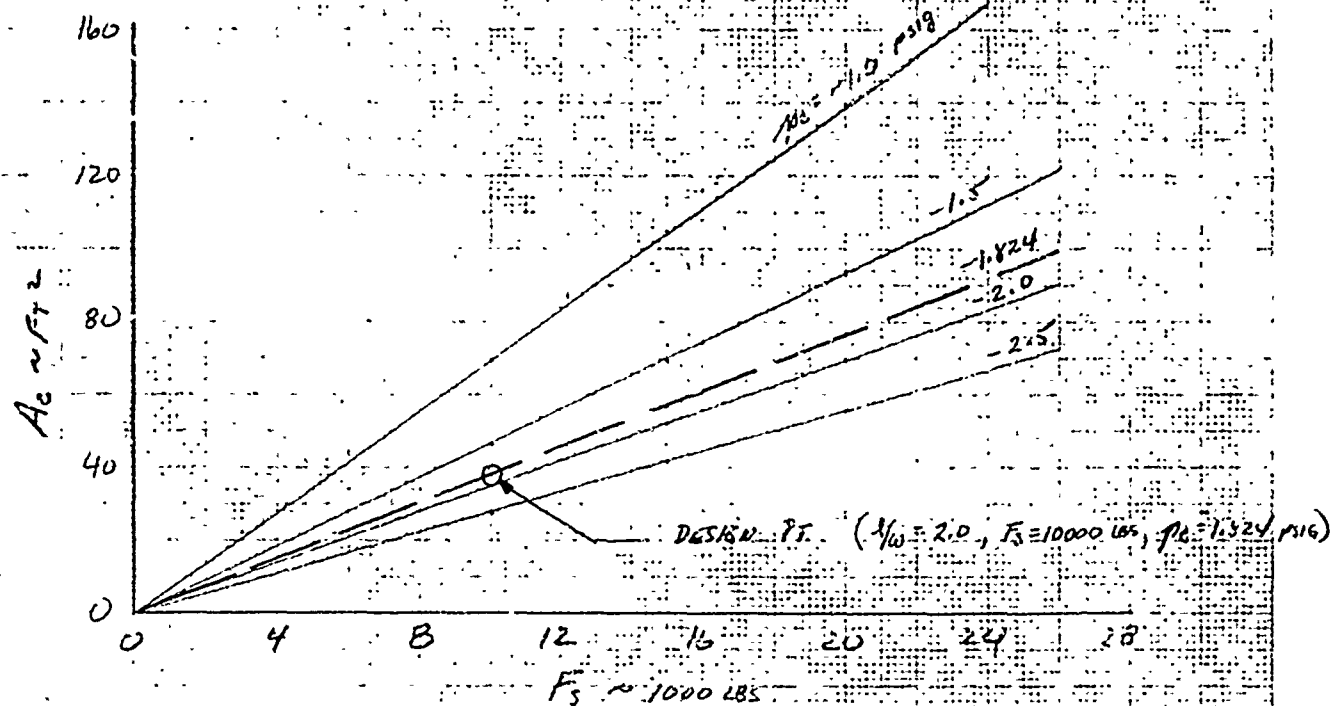PRESSURE AND LENGTH/WIDTH RATIO
ON CUSHION AREA, WIDTH, AND CIRCUMFERENCE

FIGURE 31

BERNOULLI SYSTEM

EFFECT OF CUSHION AREA ON
HOLD DOWN FORCE

$P_3 = 2180$ PSFG.

$l/w = 2.0$ CUSHION

$A_c = R^2(\pi+4)$ FT² (AREA)

$C_c = 2R(\pi+2)$ FT (CIRCUM.)

$Q = 5000 \, C_c \sqrt{20.5464}$ (CFM)

DESIGN PT. ($A_c = 281.5464 \, ft^2$, $C_c = 20.5464/ft$, $Q = 5000 \, CFH$)
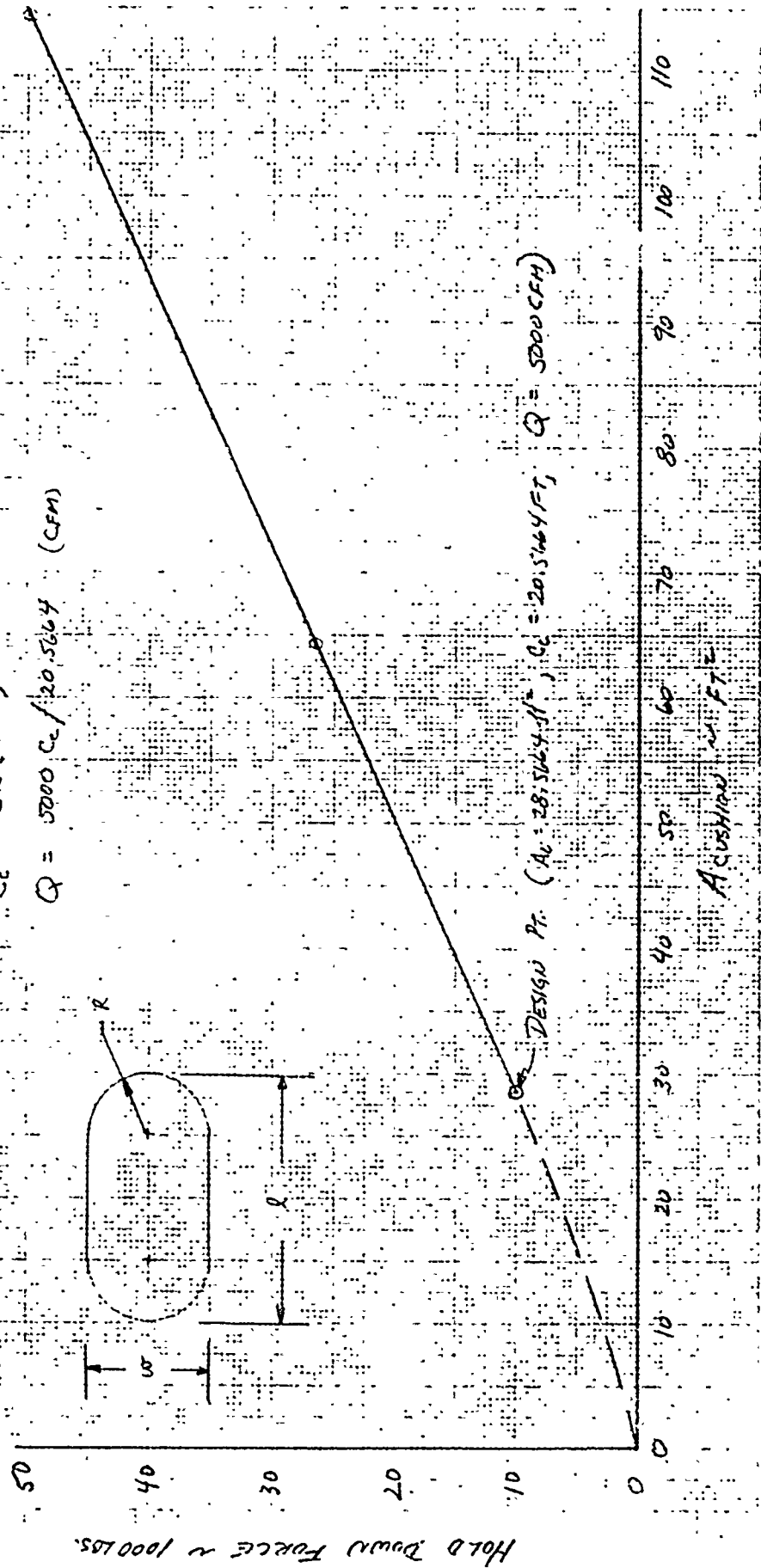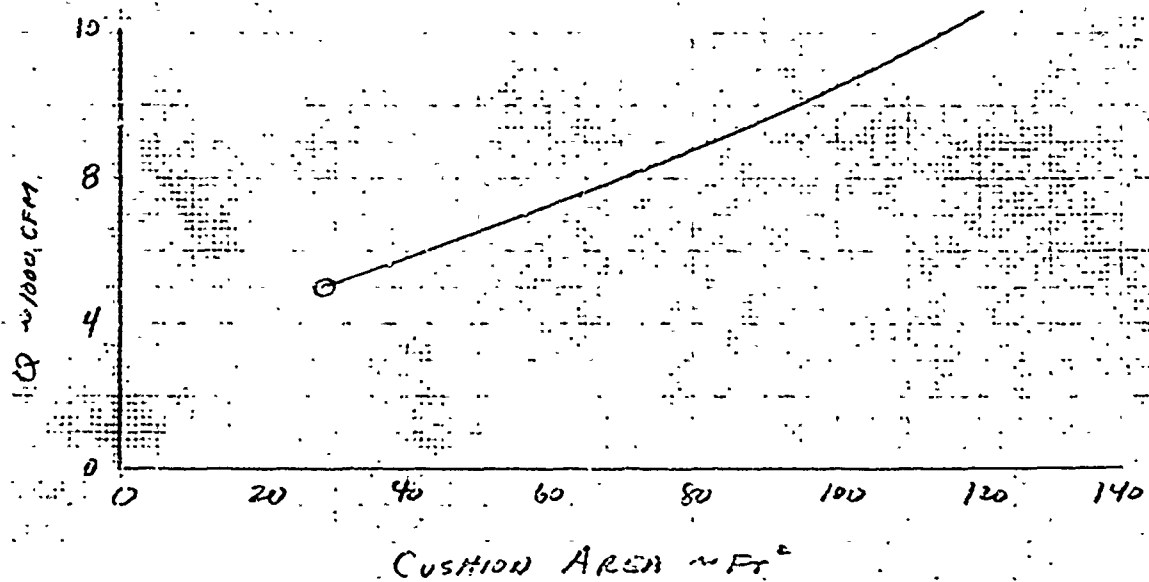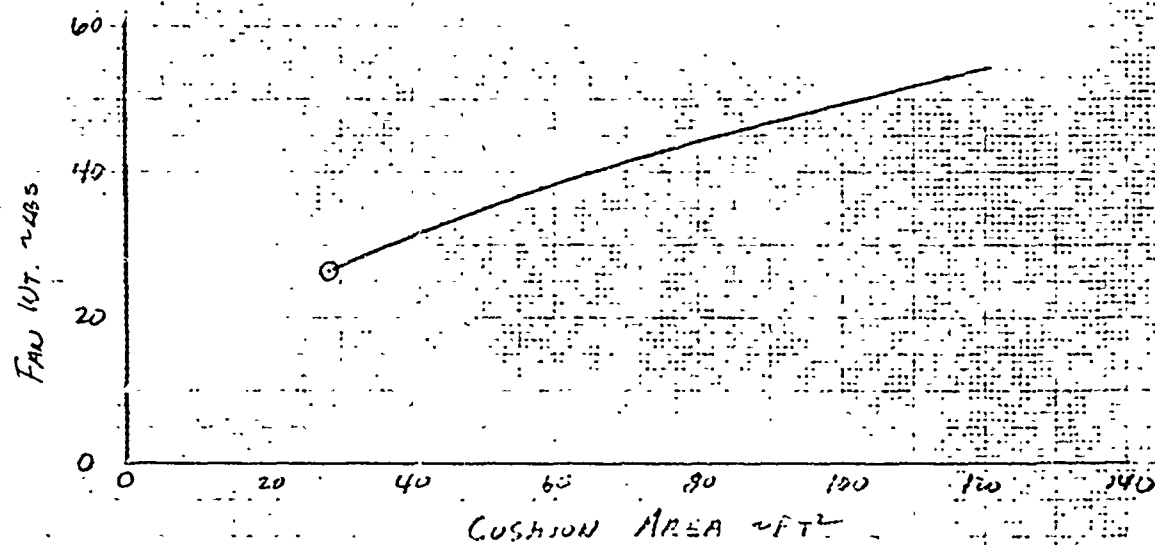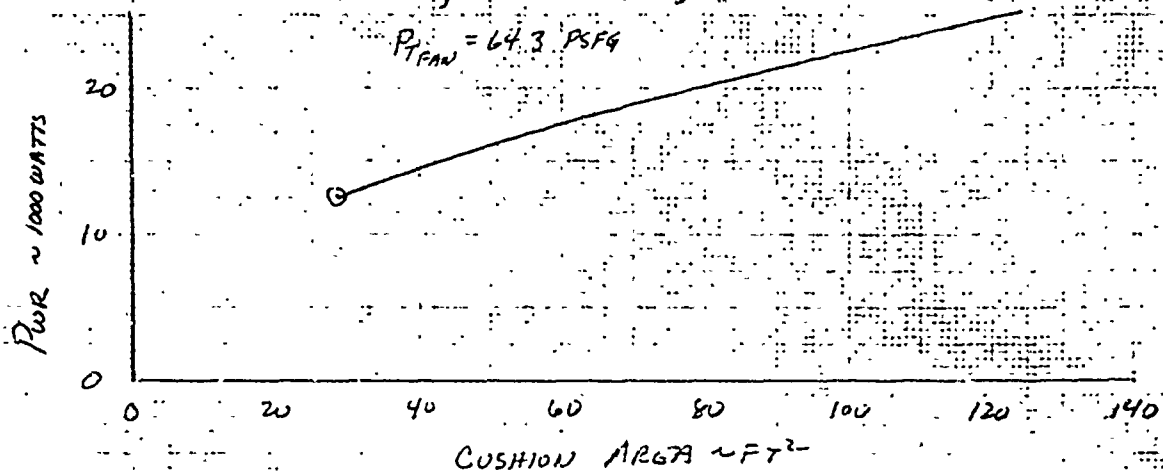
A CUSHION IN FT²

Hold Down Force ~ 1000 lbs.

FIGURE 32
BERNOULLI SYST
EFFECT OF CUSHION AREA ON
POWER, FAN WEIGHT, AND AIR FLOW
$P_{T_{FAN}} = 64.3$ PSFG

RECOMMENDATIONS AND CONCLUSIONS

It has been concluded from these conceptual design studies that all three of the systems studied could be developed into a workable system that would meet all of the requirements of this study. All of the systems have certain merits as well as problem areas. Overall, the Rigid Skirt System appears to be the simplest, most promising system, as the technical risks are very minimal. The Rigid Skirt System has most of the advantages of the other systems and few of the problems. It is our recommendation that the Rigid Skirt System be selected for further study, testing, and development.

The Bernoulli System is the smallest and lightest of the three systems. It was not recommended, however, because of the following reasons:

(1) High technical risk.

(2) Subject to damage during landing.

(3) High power requirement due to large volume flow required.

(4) Relatively large fans required.

(5) Problems associated with maintaining proper platform height in relation to deck.

The Elastic Trunk System has the best shock absorption characteristics of the three systems studied and would be the least likely to damage during landing. It was not recommended because:

(1) Very large platform required.

(2) Heaviest of the systems studied.

(3) Requires development as to elastic material and size of trunk.

(4) Requires engine bleed air or other source of air to inflate trunk.

(5) Damage to trunk could render system inoperative.

(6) Problems associated with maintaining proper platform height to minimize translation drag.

(7) Cushion platform may have to be made free floating (in relation to the retraction/deployment system to prevent asymmetric translation forces.

The Elastic Trunk may ..erit further investigation to examine the effect of trunk size to reduce the size of the platform and the overall system weight. Blowing from the bottom of the trunk (similar to ACLS) to create an air bearing could be investigated further. However, preliminary investigation indicates that the air flow and power required would increase very significantly. Also, a continuous source of air to the trunk would be required.

The Rigid Skirt System was selected because it seems to have the best features
of the other systems and the disadvantages appear to be very minor in nature.
The advantages of the Rigid Skirt System are:

(1) Relatively small, light weight package.

(2) Only minor technical risk.

(3) Good shock absorption at landing impact.

(4) Low air flow and power requirements (small fans).

(5) Low translation forces.

(6) Platform height above deck not critical.

The possible problem areas associated with the Rigid Skirt System are listed
below. However, they appear to be relatively minor in nature.

(1) Possible damage to skirt at landing.

(2) Skirt stiffness to prevent suck in, and subsequent binding
against the platform.

(3) Bellows seal to prevent leakage.

(4) Retraction of skirt for stowage.

(5) Pneumatic (or spring) skirt hold-down system will require
investigation to insure low translation drag.

It is recommended that a simple scale model test program be initiated to prove
the feasibility of the Rigid Skirt System. These tests should be qualitative in
nature and be carried out in conjunction with development studies.